New PV Micro-Modules on Standard Roof Tiles

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Abstract – Various technologies available on the solar photovoltaic cell market have been reviewed. The method of photovoltaic micro-modules implementation on standard roof tiles was shown. The possible roof tiles were chosen. Problems related to micro PV modules design and concept of final product developed at Electrotile Company have been described. It was shown that solar panel modules consisting of 6 two-cell setups on the Tysenia roofing tile generated power of 38.5 W or 42 W, depending on cell type.

Keywords – Electrotile; micropanel PV; photovoltaic; tile

Nomenclature

U_{oc}	Open Circuit Voltage
I_{sc}	Short Circuit Current
P_{mpp}	Maximum Power Point Power
U_{mpp}	Maximum Power Point Voltage
I_{mpp}	Maximum Power Point Current

1. INTRODUCTION

For many years, electricity has been produced from various types of primary energy sources. The most common were non-renewable energy sources, which include fuels such as: coal, gas or radioactive elements. However, this is increasingly criticized due to harmfulness to the natural environment. Increasing air pollution and the possibility of global temperature rise due to emission of, among others, CO₂, have stimulated interest in renewable energy sources. Currently, thermal energy is used for utility purposes and electric energy is used for own needs or is transferred to the grid or accumulate using Power-to-Gas and Power-to-Liquid [1]. There are many sources of RE (renewable energy) known that can be used to generate electricity. These include: wind and water turbines, biomass [2] and photovoltaic modules (PV). Fuel cells are renewables which use hydrogen from renewable sources. The solution that is gaining more and more popularity, both among large investors as well as among small end users, are photovoltaic modules. The photovoltaic module is constructed from a number of interconnected photovoltaic cells, which are able to convert solar energy into electricity through the use of suitable materials.

The solution in this article, namely the integration of PV panels with steel roof tiles, creates a new trend in the field of BIVP (building integrated photovoltaic). As part of the research, a proposal that meets the roofing and photovoltaic module requirements was developed.

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2. THE ORIGINS OF THE PROBLEM

The size of solar panels currently available on the market is standardized, in mm² (Table 1).

TABLE 1. DIMENSIONS OF PV PANELS AVAILABLE ON THE MARKET [3]

Dimensions, mm	Max power, W	Weight, kg
1960·991 – Polycrystalline (Fig. 1)	315–330	23
1968·992 – Double glass	320–335	28
1960·991 – Monocrystalline (Fig. 1)	320–355	23

Fig. 1. Polycrystalline and Monocrystalline solar panel [1].

Most of the PV panels are installed on the roofs of buildings or on the ground (Fig. 2). In both cases, it is necessary to use an additional frame. A home owner who wants to have a PV system on his roof must first build a roof (tiles, ceramic tiles, etc.) It is also necessary to intervene in the roof by installing specialized racks for mounting PV panels. The Electrotile Company has decided to face this problem by implementing a roofing tile integrated with a solar panel.

(a)

(b)

Fig. 2. PV panels: (a) on the roof; (b) on the ground [3].

3. METHODOLOGY OF CONDUCT

3.1. Supporting Structure

The most popular currently used roof coverings are: ceramic or cement tile, modular roofing sheet, trapezoidal sheet or sandwich panel. The last of the roof covers is used mainly in halls or industrial buildings.

The ceramic solar roof tile was introduced to the market by Tesla Company in 2017. The Electrotile Company has decided to revolutionize the solar photovoltaic market by low weight and mass production of PV roofing tiles.

As part of the analytical work conducted, roofs covering structures which have the potential of their use as the foundation for PV modules were analysed. The analysis included solutions based on materials like ceramics, cement and steel. The Tysenia and Murano tile modules (tile modules forms made of steel) were considered the most suitable construction. Both constructions are characterized by fast installation and good workability during the construction of the solution.

Selected roof coverings have been represented in virtual environment (Solid Works). This representation enabled conducting the designing procedure and finding most effective solution.

In the virtual environment, some basic simulations in terms of static overloads from photovoltaic packages made in the back-sheet panel system covering 95 % of the tile surface were conducted. Owing to this fact, maximum value of the surface which may be taken by the PV element without deteriorating modules' parameters as roof covering.

During the tests conducted, it was decided to use commercially available modular steel roofing-sheets as a substrate. The attention was given to various models available on the market. After the analysis of the possibilities of integration of solar micropanels with modular roofing sheets, it was found that the most cost-effective for use as a substrate for solar photovoltaic boards are models based on Tysenia and Murano (Fig. 3).

(a)

(b)

Fig. 3. (a) Tysenia and (b) Murano roof tiles.

Both roof tiles have a relatively large flat surface, which allows to obtain a maximum large area covered with photovoltaic cells. Both models have ribs that strengthen the surface of the roofing sheet; the installation of solar photovoltaic cells in this place (ribs) is not possible.

These roofing models allow the installation of micro-modules with dimensions not exceeding 150·320 mm.

3.2. Available PV Technologies

A typical photovoltaic cell is a semiconductor element that converts solar energy into electrical energy using a photovoltaic effect. The photovoltaic cell can be composed of two layers of semiconductor material whose design resembles a semiconductor diode.

Depending on the material used, PV cells are divided into several generations, of which the first- and second-generation cells are the most popular. Higher-generation cells are in the process of testing, therefore they have not been widely used up to now in industrial production [4]–[7].

First generation solar cells are made of crystalline silicon wafers.

Second generation photovoltaic cells are otherwise called thin-film cells due to the thickness of semiconductor coatings. Such cells are characterized by lower efficiency compared to the first-generation cells, which means that a larger usable space is required to install a setup of similar power. This group includes technologies such as CIGS, CIS or CdTe [7].

Third generation photovoltaic cells are devoid of the classic p-n junction [6]. The cells of this generation are made in silicon-free technologies and expensive materials that are often rare chemical elements. The promising technologies of third generation are cells made of organic compounds, dyes (dye-sensitized solar cells) or polymers. Currently, these technologies have various problems to overcome, such as short life span or low efficiency, which is why they are still in the research phase [7].

Monocrystalline cells are made of silicon doped with other elements in order to obtain a material of p and n type. The crystalline silica does not occur naturally in nature. It is made of molten material, e.g. using the Czochralski method.

Polycrystalline cells are the second type of PV cells belonging to the first generation. The production process begins with a block of silicon polycrystal, which crystallizes from molten silicon.

Cells produced using back-contact technology are made of crystalline silicon and are characterized by high efficiency of converting solar radiation into electrical energy. In this solution, both the positive and the negative electrodes are at the back of the cell so that there is no shading effect on the surface absorbing solar radiation.

CIS, CIGS cells are made of a mixture of copper, indium and selenium (CIS) or copper, indium, gallium and selenium (CIGS). The modules are made using relatively cheap technology when compared to silicon modules.

CdTe cells are made of cadmium telluride (CdTe). Cadmium belongs to the group of harmful elements, however its use in photovoltaic cells can be safe. Attention should be paid to modules made of cadmium telluride, if the process is not properly handled. CdTe cells have the lowest efficiency among the technologies listed above.

Bearing in mind the limitations of the available space and the need to obtain a high energy yield from the surface unit, a suitable solution may be the use of high efficiency cells, e.g. silicon cells made in back-contact technology or classic silicon cells made in monocrystalline technology.

Cells in monocrystalline technology are available in two sizes: 125·125 mm (5 inch) and 156·156 mm (6 inch). Cells made in back-contact technology are available only in a size of 125·125 mm but polycrystalline cells are available only in a size of 156·156 mm.

Table 2 presents the most important parameters of the above cell types in both available sizes.

TABLE 2. PERFORMANCE COMPARISON OF DIFFERENT PV CELLS

	156·156 mm		125·125 mm	
Parameter	Mono	Poly	Mono	Back contact
Efficiency	18 %	17 %	18 %	22.6 %
U_{oc}	0.63 V	0.62 V	0.63 V	0.71 V
I_{sc}	8.765 A	8.495 A	5.68 A	6.08 A
P_{mpp}	4.35 W	4.14 W	2.8 W	3.5 W
U_{mpp}	0.527 V	0.532 V	0.527 V	0.612 V
I_{mpp}	8.22 A	7.92 A	5.32 A	5.8 A

U_{oc} – Open Circuit Voltage, I_{sc} – Short Circuit Current, P_{mpp} – Maximum Power Point Power, U_{mpp} – Maximum Power Point Voltage, I_{mpp} – Maximum Power Point Current.

On the basis of the above data, it can be noticed that polycrystalline cells are characterized by little less power when compared to cells made of single crystal, while they are cheaper to produce. The best electrical parameters are characterized by cells made of crystalline silicon in back-contact technology. The choice of photovoltaic technology should be made on the basis of economic analyses allowing for the selection of the optimal solution in terms of costs and electrical parameters.

3.3. Problems Related to Micro PV Modules

The first problem associated with the above-mentioned dimensions is the lack of solar panels with such dimensions on the market. The dimensions defined above (150·320 mm) may be achieved by using two 125·125 mm cells or two 130·138 mm cells. The first one has too little power. The second one requires cutting cells with dimensions 156·156 mm. The least troublesome would be the use of cells with dimensions of 125·125 mm, however, their use does not lead to the maximum available surface of the roofing sheet, which translates into the reduction in the power of the entire module.

Dimensions of the applied substrate enable the use of two interconnected series of cut cells with dimensions of 130·138 mm. This results in a better use of the active surface of the roofing sheet and higher power output from a single photovoltaic micro module (Table 3).

TABLE 3. POWER OBTAINED FROM A SINGLE MICROMODULE

	130·138 mm		125·125 mm	
Parameter	Mono	Poly	Mono	Back contact
Efficiency	18 %	17 %	18 %	22.6 %
P_{mpp}	3.2 W	3.05 W	2.8 W	3.5 W

Table 3 shows that the highest power can be obtained using back contact cells with dimensions of 125·125 mm. However, they are more expensive than monocrystalline cells.

An alternative is the use of photovoltaic cells with dimensions of 130·138 mm. Their use requires cutting to a complex dimension. It can be carried out by using high-speed grinders with a diamond disc or with a laser (YMS-50 scribing machine). Fig. 4 shows what the cell edge looks like for both types of cuts.

Fig. 4. Cutting: (a) without and (b) with laser.

In addition, the mechanical cut of photovoltaic cells has disturbed silicon structure on the cutting line, which causes them to crack during the soldering and lamination process.

The photovoltaic solar micromodule proposed by Electrotile Company would consist of the layers shown in Fig. 5 (130·138 mm) and Fig. 6 (125·125 mm): tempered glass protecting the module from the top, two layers of EVA film, photovoltaic cells, two layers of EVA foil, busbars deriving electricity from the photovoltaic module, back-sheet film.

Fig. 5. Micromodule 2 cells 130·138 mm proposed by Electrotile Company.

Fig. 6. Micromodule 2 cells 125·125 mm proposed by Electrotile Company.

Application of such 6 micromodules from cut-off photovoltaic cells on the Tysenia roofing tile will allow to achieve solar photovoltaic cell parameters with the parameters shown in Table 4.

TABLE 4. SOLAR PHOTOVOLTAIC CELL PARAMETERS DEPENDING ON THE CELLS USED

	130·138 mm	125·125 mm
Parameter	Mono	Back contact
Efficiency	18 %	22.6 %
U_{oc}	7.56 V	8.52 V
I_{sc}	6.46 A	6.08 A
P_{mpp}	38.48 W	42 W
U_{mpp}	6.324 V	7.34 V
I_{mpp}	6.05 A	5.8 A

Table 4 shows that it is more cost-effective to use back-contact cells with dimensions of 125·125 mm.

4. CONCLUSIONS

It is possible to develop solar panel modules consisting of 6 two-cell setups on the Tysenia roofing tile and generating power of 38.5 W or 42 W. The first version contains cut monocrystalline cells with dimensions 130·138 mm and the second version contains back contact cells with dimensions of 125·125 mm. In terms of energy efficiency, more reasonable solution is the second version of the roofing sheet. However, it requires the use of more expensive photovoltaic cells and a less standard solar panel installation line.

The final concept of solar photovoltaic roofing proposed in the Electrotile Company is shown in Fig. 7.

Fig. 7. Solar photovoltaic roofing proposed in the Electrotile Company.

The photovoltaic roofing tile designed by Electrotile will be able to fully replace traditional panels installed on the roof of the building. Comparison of the sample parameters of the 1 kWp PV Roofing installation with traditional installation is presented in Table 5.

TABLE 5. COMPARISON OF A TRADITIONAL
INSTALLATION WITH 1 kWp PHOTOVOLTAIC ROOFING INSTALLATION

	130·138 mm	125·125 mm	156·156 mm PV panel
Parameter	Mono	Back contact	Mono
Number of items	25	25	3
P_{mpp} One item	38.5 W	42 W	320–350 W
P_{mpp} entire installation	962.5 W	1050 W	960–1050 W
Installation area	10.76 m ²	10.76 m ²	5.014 m ²
dimensions of the installation	6.022·1.787 m	6.022·1.787 m	5.090·0.985 m

Table 5 shows that the installation using Electrotile photovoltaic roofing will occupy an area about twice as large as the installation with traditional panels.

Fig. 8 shows an example of a 1 kWp installation installed on the roof.

Fig. 8. Traditional 1 kWp installation on the roof.

Fig. 9 shows an example of a 1 kWp installation using photovoltaic roofing tile.

Fig. 9. 1 kWp installation with photovoltaic roof tiles.

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