Building Integrated Photovoltaic (BIPV): Implementing Artificial Intelligent (AI) on Designing Rooftile Photovoltaic

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ABSTRACT

The monocrystalline photovoltaic (PV) is integrating into the natural clay used to fabric the terracotta rooftile. The enlargement of the rooftile's dimension increased the power output of the PVs. This paper describes briefly the technology of building integrated photovoltaic (BIPV) development and integration to buildings and houses, especially by using artificial intelligent (AI) while composing and designing the terracotta rooftile PV. The examination of property's parameter namely dimensions of the terracotta rooftile PVs on top of the house, the voltage, current, power, and efficiency of the PVs themselves were also considered. As the examination run, we also compare the results to the convenient mounted rooftop PV. The results showed that the output power of the PV reached its maximum power as the dimension of the terracotta rooftile PVs enlarge to fully cover the roof.

1. Introduction

Building integrated photovoltaic (BIPV) refers to PV systems integrated with the building phase of an item. It means that they are constructed along with the item and also planned together with it. The task requires the cooperation of many different experts, such as architects, civil engineers and PV system designers. BIPV, especially rooftile photovoltaic (PV) is one long term investments that use solar radiation to generate clean electric power. BIPV rooftile installation coincides with a re-roofing effort avoided re-roofing cost and used to fund the installation of BIPV roof tile, which significantly provide immediate environmental benefits (no CO2 emission) [1]. Silicon materials and thin film technologies are the most commonly used to fabricant the roof tile PV. Mostly PV cells are on sloped roofs and flat roofs [2]. In reference [2] it also states that the concept of building integrated solar cells follow the general development of PVs. The common used material is high-grade silicon which is processed with negatively and positively charged semiconductors; phosphorous and boron. As the light energy from the sun hits the photovoltaic cell, electrons are freed to flow from the negative phosphorus to the positive boron. The current produced from the electric potential flowed through a metal grid covering the cell and external circuit. In the authors' previously study the typical silicon materials that used as PV materials are described in details [3].

As we commonly reckoned that the basic material of tile is clay that can withstand damage from tornadoes, hurricanes or winds up to 125 miles per hour and even earthquakes [4]. While the roof tiles are constructed on top of the house, then PV modules are mounted on those rooftiles. Nevertheless, the integrated PV inside the rooftile is developed and being used in most European houses. Figure 1 shows the different of those rooftop PV's technologies, Figure 1(a) shows the installation of PV on top of the rooftile, while Figure 1(b) shows the fully integration of PVs into the rooftile. In addition, Table 1 lists the comparison of the sample parameters of 1-kWp PV roofing installation with traditional installation.

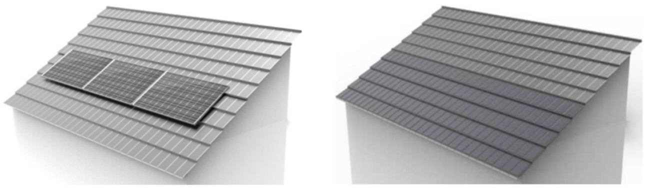
The performance of solar cells is reduced when the module temperature rises, especially in monocrystalline and polycrystalline modules. As a result, an air gap beneath the module is necessary to reduce temperature [2]. Figure 2 shows the clay looking mounted rooftiles PV. The solar cells capture energy from the sun and turn it into electricity, which is passed through the inverter and converted into a form that can be used to power the house. By storing the power and not returning it to the grid, the use of power can be controlled, paid, and saved.

According to reference [5], rooftile PVs are usually designed to resemble the terracotta rooftiles as much as possible. The rooftile PVs are often inserted in a geometrically defined portion of the roof next to the terracotta rooftiles. The visible panel height is chosen to be equal to the row height (e.g. of the order of 40cm in typical roof tiling). This ensures a perfect optical blending in of the rooftile PVs with the terracotta rooftiles. The width of the rooftile PV varies from small (0.30m) to large (1.60m). Smaller tiles have the advantage of greater roof filling and best aesthetics. Larger tiles have potentially a lower cost level. Rooftile PVs can be glazed or foil-based on i.e. polymer membranes.

Many different aesthetically appealing outcomes can be achieved using various colors and transparency of the rooftile PVs. The modules provide sun protection by transmitting daylight. The distance between the cells of the integrated PV modules is determined by the degree of transparency and the parameters for producing energy, typically the gap is between 3 to 50 mm. Diffuse daylight is transmitted through the gap between cells. Though the terracotta rooftile PVs are creating power, they also provide both shading and natural lighting [2].

In order to design the integrated rooftile PVs, the property's parameters of different BIPV product might involve different values. The artificial intelligent (AI) is used to determine the transparency of the different materials mentioned of rooftile PV. Terracotta and designer ceramic take as considerations for the rooftile PVs' designs.

This paper content is as follow, section introduction describes the trends of rooftile PVs as it comes from the clay materials. Section methods describes the process of the preparation of terracotta rooftile PVs, the flexibility design, and how the AI plays its roles in the designing process. Section results and discussion describes the testing method of the rooftile PVs to see all the evaluation of BIPV involve several properties, e.g., solar cell efficiency (η), maximum power point (Wp), open circuit potential (V), short circuit electrical current (A), and fill factor (FF). Finally, in section conclusion, all the discussion materials are concluded.



(a) PV Mounted on rooftop (b) PV integrated in the rooftiles

Figure 1. Typical PVs installation technologies [4]

Figure 2. Clay looking rooftile PV [7]

Table 1. Comparison of PV roofing installation [6]

Parameter	Type of PV panel	
	Mono (130*138) mm	Mono (156*156) mm
P_{mpp} One item	38.5 W	42 W
P_{mpp} Entire installation	962.5 W	1050 W
Installation area	10.76 m^2	5.014 m^2
dimensions of the installation	6.022*1.787 m	5.090*0.985 m

2. Methods

This section describes the clay looking rooftile PV or mostly known as terracotta as a natural clay product that has been used throughout the ages. This terracotta tiles are manufactured using prepared clays that are kiln-fired to temperatures of 1100°C, resulting in a strong yet lightweight roofing material of exceptional quality [8]. High quality premium finish of the terracotta. Various finishes are within the available choices namely fully glazed, semi-glazed, and unglazed rooftile PVs, respectively.

2.1 Terracotta rooftile PVs: preparation and flexibility design

The outstanding color performance of glazed, semi-glazed, and unglazed tiles is achieved during the firing process at temperatures of 1100°C. The process known as vitrification though as the results it provides a finished tile resistant to harsh UV exposure. The color is “sealed in” and remains vibrant for years to come [8].

According to reference [9], there are numerous advantages to using terracotta rooftile PVs to upgrade individual residence, the most important thing is that they are environmentally friendly because they are produced of natural clay and last for a long time. Here are the differences between glazed and unglazed terracotta rooftile PV: i) Glazed terracotta rooftile PVs - glazed terracotta rooftile PVs have a coating that comes in a variety of colors and tints. Semi-glazed and fully glazed terracotta rooftile PVs are the examples. Glazed terracotta rooftile PVs have the advantage of being more durable and absorbing less moisture than unglazed ones. ii) Unglazed terracotta rooftile PVs - unglazed rooftile PVs are not pre-coated, giving them a rustic look that some people prefer since it keeps the original clay coloration. Unglazed rooftile PVs, on the other hand, are best utilized in places with minimal rain since they are porous and do not have a protective covering, so they collect water and decay faster than the glazed rooftile PVs. Figure 3 shows the terracotta rooftile PVs physical design, fully glazed, semi-glazed, and unglazed, respectively.

Embedding solar roof panels in a material that resembles what is often used for roofing must consider a certain height where one can see the dark cells more or less invisible from the street. An Italian company has making rooftiles PVs that perfectly mimic materials such as terracotta. This Italian company inserts the PV cells inside a polymeric compound that mimics common roofing materials such as terracotta. It's non-toxic and recyclable, and it's designed to handle high static stresses while being impervious to atmospheric agents and chemical solvents. "It's all about density: there has to be enough to trick the eye, but not too much to obstruct the sun's beams," this company explained [11].

The flexibility design of the terracotta comes in three profiles; wave, Artline and shingle. While the terracotta rooftile PVs offer two distinct profiles; French and Swiss, due to provide great design flexibility to achieve a wide range of house designs and the solar cells' efficiency [8].

(a) Fully glazed (b) Semi-glazed (c) Unglazed

Figure 3. Product of terracotta rooftile PVs [10]

2.2 Artificial Intelligent (AI) roles

Due to technical requirements of the terracotta rooftile PVs, AI as part of production process must put into account. AI is used to determine the transparency of the different glazed materials of terracotta rooftile PVs. Complete visual fusion with an object is used as AI's tool. Through the design combinations of modules/cells/back-sheets, and the requirements to achieve maximum solar glass light transmission, it is then thoroughly achieved its best energy yield, therefore cell arrangement and gaps between solar cells are adjusted for best effect can be ignored.

The possible customizations that can be applied by adjusting the size and shape, color of glass, back-sheet, solar cells arrangement, and their transparency. It aims to deliver visually appealing and cost & energy efficient roofing solutions, despite changing sun illumination. It is a smart-way to fight CO2 emissions and lower the carbon footprint.

Figure 4 illustrates the visual fusion of maximum solar glass transmission that can be achieved by adjusting the number of rooftile PVs cells. PV modules that are using glass technology and being integrated to the rooftiles, ensures the needed characteristics similar to terracotta rooftiles.

2.3 Property's test method

The testing method of the rooftile PVs is conducted to get all the evaluation results for the BIPV that involved several property's parameters, namely solar cell efficiency (η), maximum power point (W_p), open circuit potential (V), short circuit electrical current (A), and fill factor (FF). The following property parameters [2]:

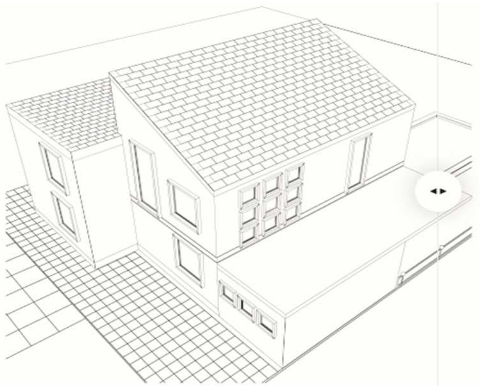
- Solar cell efficiency (η)

$$\eta = \frac{P_{max}}{(EA)} \tag{1}$$

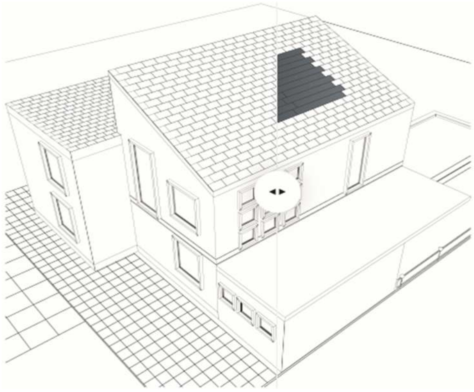
where P_{max} is the maximum power point, E is the input light irradiance in W/m^2, and A is the surface area of the solar cell in m^2.

- Maximum power point (P_{max})

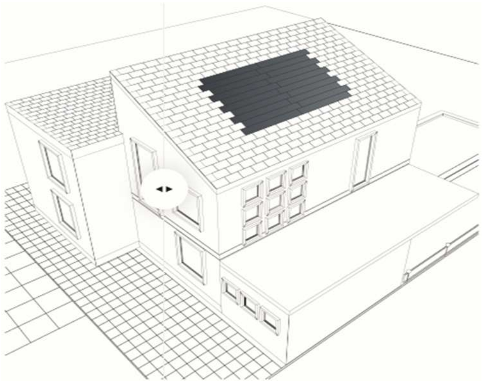
$$P_{max} = (UI)_{max} \tag{2}$$



(a) no installed rooftile PVs



(b) less amount of installed rooftile PVs



(c) large amount of installed rooftile PVs

Figure 4. Complete visual fusion of installed rooftile PVs

where U is the operating voltage, and I is the operating electrical current.

- Fill factor (PP)

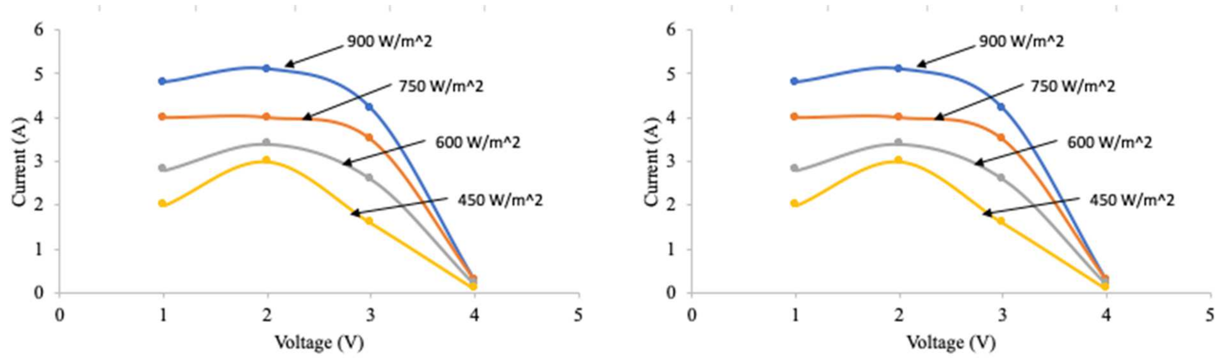
$$FF = \frac{P_{max}}{(U_{OC} * I_{SC})} = \frac{(UI)_{max}}{(U_{OC} * I_{SC})} \quad (3)$$

3. Results and Discussion

This section discusses the testing method of the rooftile PVs to see all the evaluation of BIPV involve several properties, e.g., solar cell efficiency (η), maximum power point (W_p), open circuit potential (V), short circuit electrical current (A), and fill factor (FF).

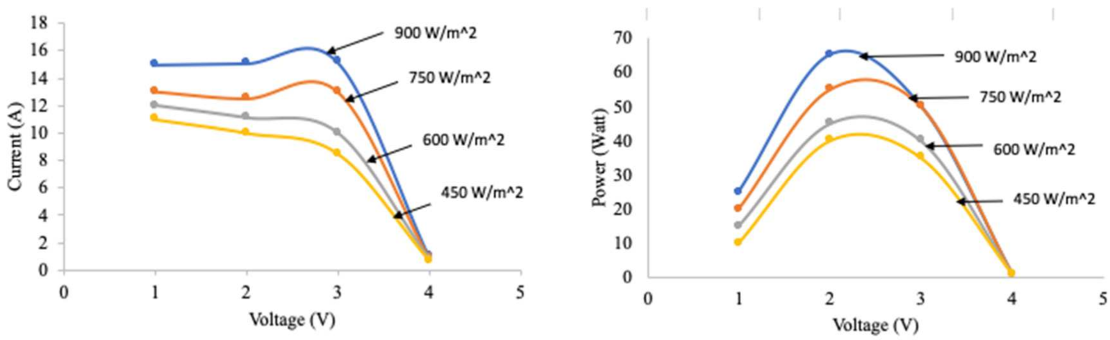
By using the equation (1), (2), and (3), respectively, and refers to the data that given from Table 1, the evaluation of property's parameters of monocrystalline mounted rooftop PVs with the dimensions of (130*138) mm, and monocrystalline integrated rooftile PVs with the dimensions of (156*156) mm, respectively. Assumed that the input light irradiance (W/m^2) is up to 900 W/m^2, then the characteristic of current-voltage and power-voltage are illustrated in Figure 5 and Figure 6, respectively.

As we can see from Figure 5, the characteristic of voltage and current of the monocrystalline mounted rooftop PVs with the dimensions of (130*138) mm with the input light irradiance (W/m^2) within the range of 450-900 W/m^2, as the lowest irradiance (450 W/m^2) the current reach 3 Amperes at 4 Volts. The higher the irradiance, takes the current increase but the voltage decrease, while the power reaches 40 Watts at 2 Volts voltage.



(a) current-voltage characteristic (b) power-voltage characteristics

Figure 5. Current-voltage and power-voltage characteristics of monocrystalline mounted rooftop PVs (130*138) mm



(a) current-voltage characteristic (b) power-voltage characteristics

Figure 6. Current-voltage and power-voltage characteristics of monocrystalline integrated rooftile PVs (156*156) mm

In addition, as in Figure 6, the characteristic of voltage and current for monocrystalline integrated rooftile PVs with the dimensions of (156*156) mm with the similar input light irradiance, the current reach 11 Amperes at 4 Volts. The higher the irradiance, the higher the current increase but the voltage decrease, while the power reaches 60 Watts at 2 Volts voltage.

4. Conclusion

This paper describes briefly the technology of BIPV development and integration to buildings and houses by implementing AI while designing terracotta rooftile BIPV. As the natural clay used to fabric the terracotta rooftile, the monocrystalline PV is integrating into the terracotta rooftile. Then it examined the property parameters by comparing the results to the mounted rooftop PVs. We can conclude that by using terracotta integrated rooftile PVs, the enlargement of the rooftile's dimension increased the power output of the PVs.

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