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Experimental Installation of a Hybrid Photovoltaic/thermal (PV/T) Solar System

Konstantin Kostov, Koycho Atanasov, and Atanas Atanasov

***Abstract* – The constant increase in energy demand as a result of the growth of the Earth's population, the development of industry, climate change, the rising prices of fossil fuels, are all prerequisites for the search for alternative energy sources. Such energy sources (although with limited application in some places) are renewable energy sources. They are considered renewable or inexhaustible and include wind energy, solar energy, biomass energy, hydroelectric energy, geothermal energy and others. Solar photovoltaic panels currently available on the market convert about 20–25% of the incident solar radiation into electricity. Most of the absorbed energy is dissipated into the environment, being converted into heat. This heat increases the temperature of the photovoltaic panels, thus reducing their efficiency. In recent years, much work has been done to improve the energy efficiency of these installations. One such method is the development of hybrid photovoltaic and thermal collector systems. The advantage of this system is that it generates electrical energy and allows the absorption of thermal energy. Developed in this way, the system increases its efficiency. The purpose of this article is to present the design and construction of a hybrid PV/T system. First, the development of the supporting structure of the photovoltaic panels is described with its possibilities for changing the geographical orientation and installation inclination of the panels. Then, the construction of a hybrid system is presented, with an added solar thermal installation. The possibilities for conducting experiments and the measuring equipment used are described. The laboratory installation presented in this article would allow, in the future, the conduct of numerous experiments in order to evaluate the performance of such a PV/T system. The results obtained would allow the limits of applicability and usability of the facility to be determined.**

***Keywords* – Energy efficiency, hybrid PV/T system, solar photovoltaic panels, solar thermal installation.**

I. INTRODUCTION

In the context of increasing energy needs and the need to decarbonize the building sector, this work proposes an approach that intelligently combines several energy flows. Modern building architecture allows for efficient energy generation through solar photovoltaic panels or solar thermal collectors mounted on the roof or facade of the building. Since it is not always possible to orient them optimally, it is necessary to increase the energy yield from each facade element with a suitable orientation. Due to these conditions, there are numerous works in the literature related to the integration of solar systems into the facade of the building [1], [2], [3], [4], [5]. However, the possibility of installing the two main types of active solar energy devices is not always available. In addition, the low energy conversion efficiency of photovoltaic panels, despite the high absorption of solar radiation, leads to an increase in the temperature of the cell, further reducing its efficiency.

There are different designs of hybrid photovoltaic/thermal (PV/T) systems. There are two main concepts for developing such installations - flat (PV/T) and concentrating (PV/T) collectors [6], [7]. The classification can also be made according to the type of working fluid used by the thermal installation. According to this characteristic, they can be a water PV/T collector, a combination of water/air PV/T collector and an air PV/T collector [8], [9].

In general, the design of flat (PV/T) collectors consists of a bearing structure, a supporting structure for the panel, a PV panel (glazed or unglazed) and an absorption collector below. The collector attached below cools the PV module, while at the same time removing the obtained heat energy in the form of hot air or hot water.

II. SUBSTANTIVE PART

According to the recommendations made in [10], [11], [12], a physical model of a hybrid PV/T installation was developed and constructed. The model was created based on the analysis of energy transfer due to thermal conductivity, convection and radiation. The possibilities for conducting full-scale experiments, taking into account many factors affecting the operation of the physical model, would allow it to be used to predict the amount of heat released by the system and the output power. In turn, this would allow the efficiency of the system to be investigated and algorithms to be developed to be used as a simulation for this system.

When creating the physical model, the leading criteria were its functionality and the ability to determine a number of parameters that affect the operation of the system.

The ability to change the geographical orientation and the angle of inclination of the photovoltaic panels relative to the horizon (with a heat absorption system installed below them) allows the compilation of a heat balance of the installation and determination of the electrical efficiency of the facility.

The PV/T module stand designed in this way allows the measurement of the mass flow rate, the inlet and outlet temperature of the working fluid.

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Assoc. Prof. PhD Eng. Konstantin Kostov, TU-Sofia, IPF - Sliven, Department “MMT", Sliven, Blvd. "Burgassko shose" №59 (konstankostov@tu-sofia.bg);
Prof. PhD Eng. Koycho Atanasov, TU-Sofia, IPF - Sliven, Department “MMT“, Sliven, Blvd. "Burgassko shose" №59 (koycho_atanasov@abv.bg);
Assistant Professor Atanas Atanasov, TU-Sofia, IPF - Sliven, Department “MMT“, Sliven, Blvd. "Burgassko shose" №59 (atanas_d_atanasov75@abv.bg)

The possibilities for changing the design of the absorber plate, such as the distance between the tubes, the diameter of the tube, the number of tubes, the way the tubes are arranged relative to the PV module, are another design element that can be investigated.

Fig. 1 shows a diagram of the supporting structure of the installation. The proposed structure of the tracker is made of a stable base, complete with movable steel profiles in which two photovoltaic panels are mounted. The system is single-axis, which allows, by fixing, changing the angle from the extreme horizontal to the extreme vertical position through 15 degrees. The type, size and directions of movement of the positioners are determined depending on the specifics of the application.

During the design and manufacture of the structure, special attention was paid to the reliability, stability and operational durability of the system, taking into account the impacts occurring during its operation.

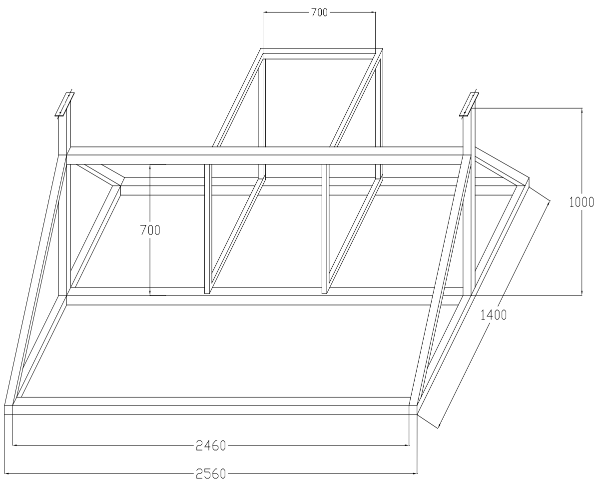
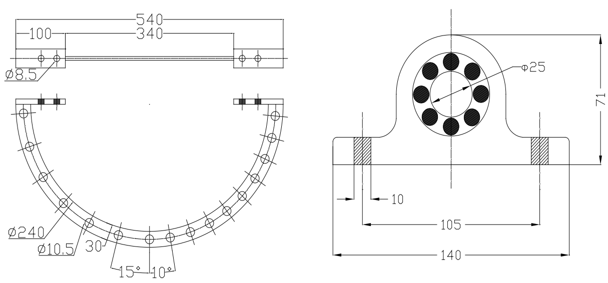


Fig. 1 Supporting structure of the installation

Fig. 2 shows the mechanism for fixing the angle of inclination (position A) of the panels and the bearing boxes (position B), guaranteeing the strength of the structure. The entire structure in assembled form is shown in Fig. 3.



A) B)

Fig. 2 Main elements of the supporting structure of the installation:
A) angle fixing mechanism;
B) bearing box

The designed supporting structure allows several possibilities for implementing different configurations of thermal collectors mounted under the photovoltaic panels. Initially, two structures are provided - one with a parallel tube bundle (Fig. 4) and one with a serpentine tube (Fig. 5). The characteristic of both structures is that the finished PV/T panel has thermal insulation at the lower end, enclosed in a common box. Fig. 6 shows the method of mounting the PV panel and the tubes from the thermal collector.

Fig. 3 Picture of the constructed structure

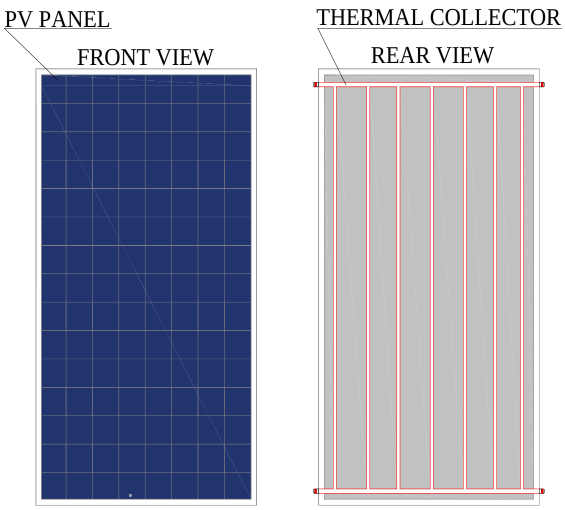


Fig.4 Parallel tube bundle design of the thermal collector

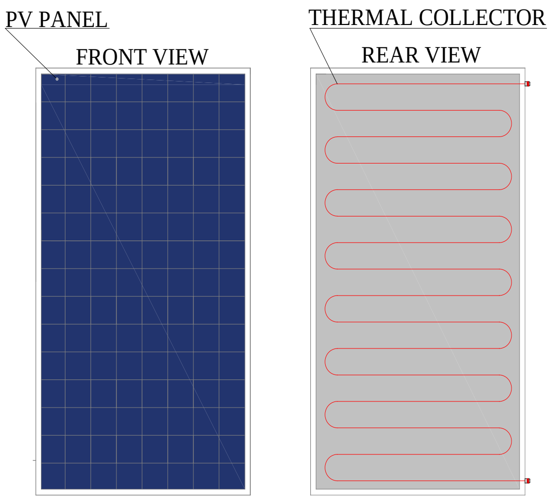


Fig. 5 Construction with a serpentine tube of the thermal collector

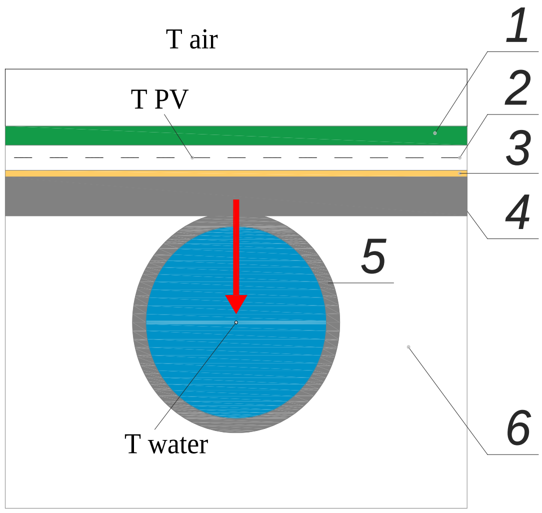


Fig. 6 Method of mounting the PV panel and the tubes from the thermal collector.
1-glass; 2-PVpanel; 3-thermal paste; 4-absorber; 5-pipe; 6-thermal insulation

III. RESULTS

The front side of the PV/T module is the same as the normal PV module, while a copper tube is welded under the absorber plate, according to the above-mentioned structures. The module receives solar radiation, converting part of it into electricity generated by the PV cells, while the rest is converted into waste heat, most of which will be absorbed by the cooling fluid (water) flowing in the tube.

This section presents a detailed mathematical model of the elements that make up the photovoltaic thermal (PV/T) panel.

The calculation of the power generated by a photovoltaic panel with a given area is determined according to equation (1) [13], [14].

$$P_{elec} = I_T * \eta_{PV} * A_{PV} \text{ , [W]} \quad (1)$$

where:

I_T – the incident solar radiation at the collector plane, [W/m^2]. It is measured directly using a solarimeter;

η_{PV} - photovoltaic panel efficiency;

A_{PV} - area of the photovoltaic panel, [m^2]

The efficiency of a photovoltaic panel can be calculated using the standard test conditions (STC) according to equation (2). The constants in the equation are according to the manufacturer's documentation.

$$\eta_{PV} = \eta_{STC} - 0,0035 * (T_{PV} - T_{PV,STC}) \quad (2)$$

As mentioned above, the cooling of the photovoltaic panel will be done with water, through a different configuration of the tubes. The amount of heat removed from the photovoltaic panel according to equation 3 will be:

$$Q_w = m_w * c_p * \Delta t \text{ , [W]} \quad (3)$$

where:

m_w - the mass flow rate of the heat carrier, [kg/s];

c_p - the specific heat capacity of the coolant, [J/kg.K];

Δt - temperature difference between the outlet and inlet of the thermal collector, [K].

The total amount of energy converted and absorbed by the photovoltaic thermal collector (PV/T) is represented by equation 4:

$$Q_{(PV/T)} = P_{elec} + Q_w \text{, [W]} \quad (4)$$

The presented equations can be used to determine the respective efficiency of the proposed PV/T and conventional PV panel designs.

Since the presented hybrid PV/T system is designed for outdoor operation under conditions of significant variations in climatic conditions on the one hand and hourly variations in solar radiation and ambient temperature on the other, a system for controlled cooling of the PV panel is provided for the PV/T module. The presence of such a system not only limits its excessive heating, but is also expected to increase the total output power of the PV/T module.

IV. CONCLUSION

The conducted research is the beginning of the creation of a laboratory installation of a PV/T module. The proposed designs will be investigated, but this does not limit in any way the development of the installation. The capabilities of the system allow for the conduct of numerous experiments, allowing the consideration of many factors affecting the operation of the installation. The proposed mathematical model can be expanded and adapted for conducting simulation model studies with the appropriate software.

Focusing on the assessment of the energy characteristics and economic viability of the system, the goal of future research is the optimization of the installation, with the aim of improving the performance of the system, its applicability and adaptation to different geographical regions.

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