An experimental study on energy generation from photovoltaic-thermal hybrid systems

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Abstract: *Solar energy is one of the leading renewable energy sources because of its great potential, affordability of the individual system prices, zero emission and no noise emission. 21st century will be based on renewable energy sources, with strict environmental measures, primary energy use will mainly consist of a combination of (different) clean energy sources among which solar energy will play a leading role. Two technologies for harnessing the energy of the sun are photovoltaic cells (PV) and solar collectors. Photovoltaic cells (PV) exploit the visible part of the spectrum while solar collectors use the infrared part. Combining these two technologies into one provides a system that produces electricity and heat at the same time using all parts of the solar spectrum. These systems are known as photovoltaic thermal systems or PV/T. This paper presents the description of these systems and methods of application. Among this, this paper gives description of experimental PV/T installation at Faculty of Mechanical Engineering in Banja Luka.*
KEYWORDS*: PV PANELS, SOLAR COLLECTORS, PHOTOVOLTAIC-THERMAL SYSTEM, SOLAR ENERGY*

1. Introduction

With population growth and the development of a global economy, the need for energy is steadily rising and fossil fuels are no longer as secure a source of supply as they were in the last century. From all of the above, renewable energy sources are the focus of both scientists and decision-makers with a view to ensuring the energy stability of states and protecting the environment. Solar energy is one of the leading renewable energy sources because of its great potential, affordability of the individual system prices, zero emission and no noise emission.

PV panels and solar collectors harness solar energy by covering a certain part of the spectrum of solar radiation. Photovoltaic cells (PV) exploit the visible part of the spectrum while solar collectors use the infrared part. Combining these two technologies into one provides a system that produces electricity and heat at the same time, utilizing all parts of the solar radiation spectrum. These systems are known as photovoltaic thermal systems or PV/T. PV/T systems can produce more energy per unit area compared to a single PV panel and solar collector [1]. This paper presents the description of these systems and methods of application. Among this, this paper gives description of experimental PV/T installation at Faculty of Mechanical Engineering in Banja Luka.

2. PV/T Systems: the working principle and classification

Only 15-20% of the solar radiation that falls on the PV module is converted to electricity while the rest heats the module [2]. In other words, more than 50% of the incident solar energy is converted as heat (after deducting the reflected portion). This may lead to extreme cell working temperature as much as 50^{o}C above the ambient environment. The electrical efficiency of PV modules decreases as the operating temperature of the module rises. The electrical efficiency of the PV module depends on the material from which the module is made, as well as on the tilting angle of the panel [3], dust [4] [5], shadows [6] and the climate of a specific geographical area [7] [8] [9]. Significant impact on the reduction of PV module efficiency is the exposure to intense solar radiation and high temperatures for a long time [10].

The most critical periods for the electrical efficiency of PV modules are periods with high ambient air temperatures and low wind speeds [11]. Another problem that may occur due to the high temperature of the module is that photovoltaic cells can totally be burned [12]. From all of the above it is concluded that cooling the PV module is important and necessary. By cooling the solar cells with a fluid stream like air or water, the electricity yield can be improved. But conceptually the better design is to re-use the heat energy extracted by the coolant.

A hybrid system is a system that connects two or more energy conversion devices or one system to which multiple energy sources are integrated. The efficiency of a hybrid system is usually higher than that of single technologies. In a hybrid PV/T system, the thermal energy of the panel is absorbed by the working fluid (coolant) by the heat conduction process or by convection, the panel temperature is reduced, thereby significantly increasing the electrical efficiency of the hybrid system. The advantages of PV/T systems are:

1. photovoltaic and solar collectors use different parts of the spectrum of solar radiation. Combining the two systems into one results in a more efficient use of the entire solar spectrum;

2. PV/T system requires less space for installation than separate installation of PV panels and solar collectors;

3. when implementing the system, the PV/T system requires less material than two separate systems;

4. electrical efficiency is increased by heat dissipation from the PV module;

5. the working fluid has a higher temperature due to the heat it absorbs from the photovoltaic cells;

6. Greater overall efficiency than separate systems.

PV/T systems are divided according to: type of collector, type of coolant, material of which PV is made, mode of flow of coolant. Fig. 1 shows the main features of a flat-plate PVT collector.

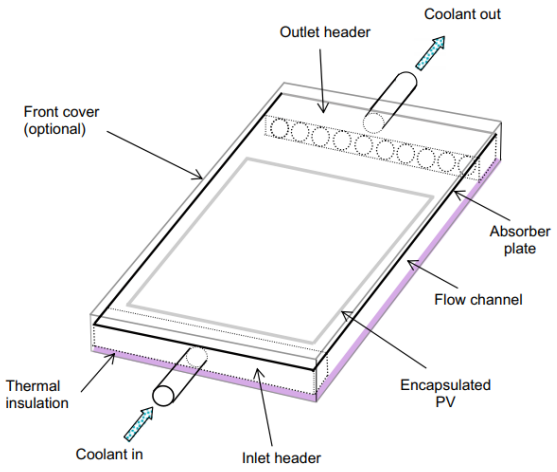

Fig.1. *Main features of a flat-plate PV/T collector [13]*

Fig. 2 shows the longitudinal cross-sections of some common air-type PV/T collector configurations whereas the cross-sectional views of some examples of the water-type designs are in Fig. 3.

Significant research has been carried out in recent years in the field of CPV/T systems (*Concentration photovoltaic/thermal system)* in order to achieve the highest efficiency of the system, ie higher electrical efficiency and higher output temperature from the system. However, when analyzing such systems, it must be borne in

mind that CPV/T systems are significantly more complex than flat plate PV/T systems, and that such systems are accompanied by a mirror-rotating device depending on the position of the sun. Photovoltaic cells in which the concentration of solar radiation is made are more expensive because of the working environment and exposure to higher radiation and high temperatures. Fig.4 is a simplified representation of the CPV/T collector.

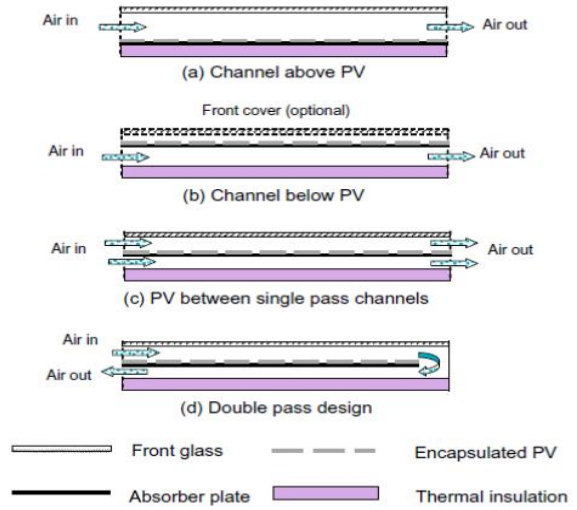

Fig.2. *Longitudinal cross-sections of some common PV/T air collector designs [13]*

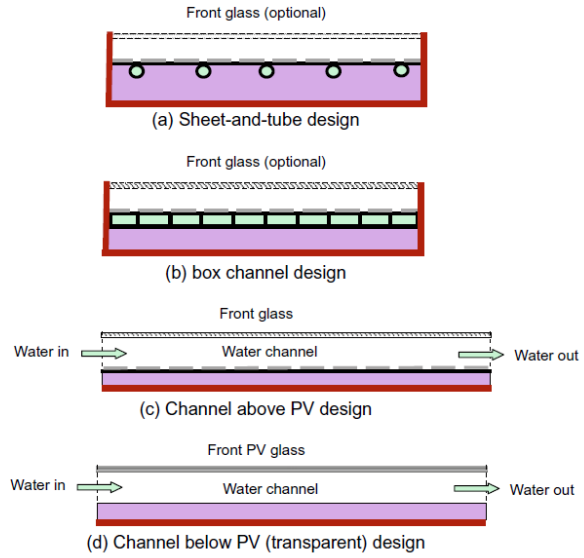

Fig.3. *Cross-sections of some common PV/T water collector designs [13]*

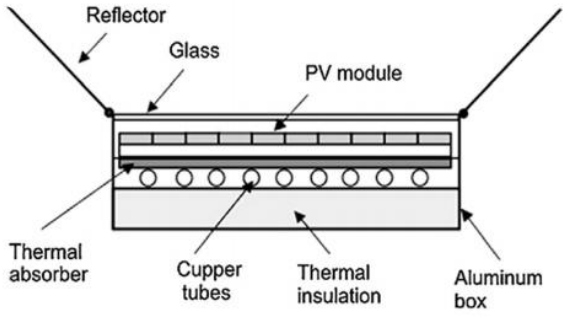

Fig.4. *Schematic of CPV/T collector [14]*

The BIPV/T (Building Integrated PhotovoltaicThermal) system is the structural, architectural and aesthetic integration of the PV/T system into the building structure of the facility [15]. BIPV/T systems use the building envelope to collect solar energy to produce electricity and heat, providing an efficient way to reduce energy consumption in the facility from other sources. Establishing a BIPV/T system as a standard in architecture but also as a functional component of a facility to replace conventional building materials for cladding would lead to a significant expansion of the use of the BIPV/T system. Given that 32% of the world's consumption is spent on buildings, this way of supplying the facility with heat and electricity is of interest for the development of NZEB buildings. The characteristics of the BIPV/T system are:

- the system is physically connected to the building;
- the system generates electricity;
- the system generates thermal energy that can be used directly in the building or through other technical systems.

Fig 5. Represents some implemented BIPV/T systems.

Fig.5. *BIPV / T water system integrated in the facade of the building [16], BIPV / T roof system [17]*

3. Experimental setup of PV/T system

Faculty of Mechanical Engineering in Banja Luka is implementing the research project "Thermodynamic Analysis and Mechatronic Synthesis of Solar Power Plants in Urban Areas" which is co-financed by the Ministry of Science and Technology Development, Higher Education and Information Society of Republika Srpska, Bosnia and Herzegovina. One of the project activities is experimental research of PV/T system in urban area. During research, it will be analyzed the possibility of obtaining electricity by conversion from solar energy as well as the thermal effects that accompany this phenomenon. Generated heat from PV panel will be used for water heating. Monitoring the trajectory of the Sun in order to obtain the maximum possible power in given climatic and meteorological conditions is a mechatronic type of a problem that is approached from the mechanical, energy/(thermal and electrical) and control aspects. The management mode is based on stored data that depends on geographical location, the use of light sensors or the methods of monitoring maximum output. The implementation of mechanical as well as control structures is different and is based on microcontrollers, programmable logic controllers, phase controllers and application of artificial intelligence. The idea of the project is to carry out scientific research that will answer the question of which solar monitoring system is the most energy efficient from the electrical and thermodynamic point of view, but also optimal in terms of the complexity of design, technical solution of mechanical part and price, and with innovative design acceptable for use in urban areas. During research it will be used monocrystal PV/T module and control monocrystal PV module (Solarfam Moncrystaline Solar Panels model SZ-100 - 36M). All measurement results (insolation, air temperature, precipitation, wind speed, data on different angles of positions of photovoltaic panels) will be used to analyze and simulate the process and find the optimal and most efficient positionsof the panels in order to obtain the maximum amount of electricity and the most efficient thermodynamic characteristics of the system. Fig.6. and Fig.7. represents 3D model of the experimental setup of PV/T system. Experimental setup will be placed in front of the building of the Faculty of Mechanical Engineering Banja Luka. Whole setup will be set in spring 2020 when will start experimental research and all measurments.

Fig.6. *Front view of the experimental setup of PV/T system*

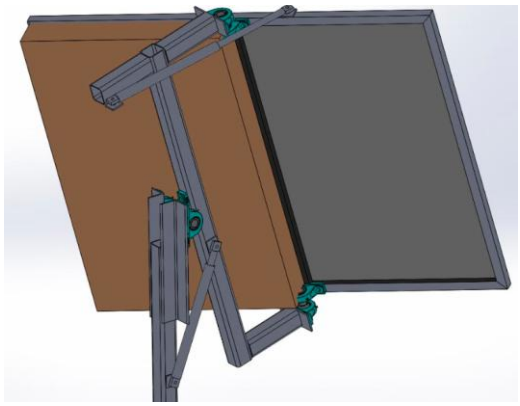

Fig.7. *Back view of the experimental setup of TV/T system*

Example of experimental setup of fix PV/T system is shown on Fig.8.

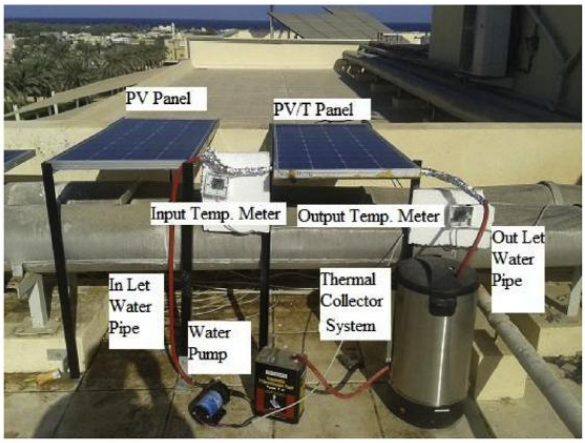

Fig.8. *Experimental setup of PV/T system andreferent PV panel[18]*

4. Conclusion

PV/T systems are systems that utilize a wider range of solar radiation while generating electricity and heat. The application of these technologies is particularly interesting in urban areas where energy requirements are high and space for the installation of solar collectors and PV panels is limited. Integration of these systems and their use in the future represents a great potential for sustainable urban development. Combining the two technologies into one, a more efficient, less expensive and more convenient system is obtained in terms of installation and maintenance.

A large number of factors affecting the operation and efficiency of the PV/T system as well as the amount of electricity and heat generated, require additional research and analysis. Duo to that, scientific project "Thermodynamic Analysis and Mechatronic Synthesis of Solar Power Plants in Urban Areas" implemented by Faculty of Mechanical Engineering in Banja Luka will contribute to this goal.

3. References

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