IMK-14 – Istraživanje i razvoj u teškoj mašinogradnji 24(2018)4, SR103-106
UDC 621 ISSN 0354-6829

Razvoj laboratorijskog sistema za merenje karakteristika fotonaponsko-termičkog panela

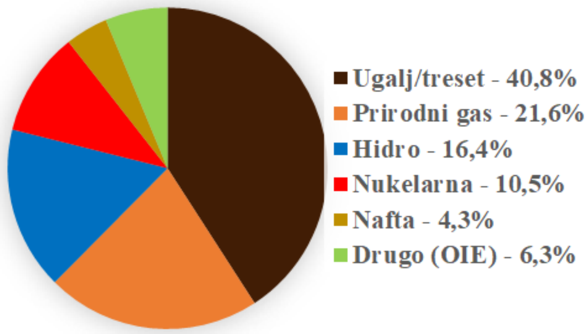
Vojislav Vujičić[1], Snežana Dragićević[1], Milan Marjanović[1*], Marko Šućurović[1], Miloš Božić[1], Marko Rosić[1]
[1]Fakultet tehničkih nauka Čačak, Univerzitet u Kragujevcu (Srbija)

Smanjenje emisije štetnih gasova u atmosferu i time zagađivanje životne sredine se u velikoj meri može podstaknuti povećanjem upotrebe obnovljivih izvora energije kao što je solarna energija, kako u cilju zagrevanja tople vode i grejanja prostora, tako i u generisanju električne energije. U ovom radu je data analiza hibridnog (kombinovanog)sistema sa PV/T panelom koji omogućuje istovremeno generisanje toplotne i električne energije, kao i komponenata prototipa laboratorijskog sistema za merenje toplotnih i električnih parametara ovih sistema. U radu su prikazani rezultati ispitivanja realizovanih merenja temperature, protoka, dobijene električne i toplotne snage u realnim vremenskim uslovima. Na osnovu analize komponenata sistema i rezultata ispitivanja predložene su izmene laboratorijskog sistema i opreme sa ciljem dobijanja preciznijih rezultata merenja.

Ključne reči: PVT solarni panel, toplotne karakteristike, električne karakteristike, solarna energija

1. INTRODUCTION

Sa povećanom potrošnjom fosilnih goriva dolazi do sve veće emisije ugljen-dioksida u životnu sredinu okolinu, pa danas najveći udeo porasta CO_2 potiče iz ljudskih aktivnosti. Radi smanjenja emisije produkata sagorevanja fosilnih goriva došlo je do veće upotrebe ekološki prihvatljivih izvora energije i razvoja novih tehnologija za dobijanje toplotne i električne energije [1].



Slika 1. Udeo različitih izvora energije u proizvodnji električne energije u svetu 2014. godine (23,816 TWh) [2]

Solarna energija se može koristiti za proizvodnju električne i toplotne energije upotrebom solarnih fotonaponskih (PV) panela i solarnih kolektora (termalni kolektori).

Upotreba solarnih kolektora je raznovrsna i ima široku primenu od solarnog zagrevanja vode u domaćinstvima, zagrevanju prostora, solarno podržano hlađenje kao i zagrevanje u industrijskim procesima. Zhanga i drugi (2012) navode da više od 90% svetski instaliranih solarnih kapaciteta čine solarna toplotna postrojenja, tako da je to najisplativije tehnologija obnovljive energije koja ima ogroman potencijal na globalnom tržištu [2].

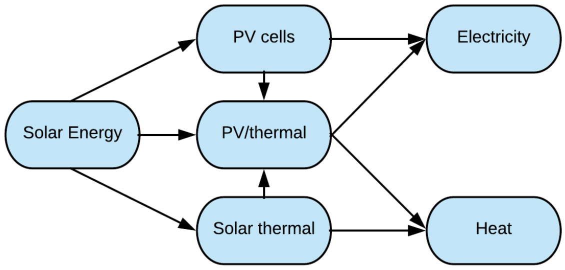
Korišćenje solarne toplotne i fotonaponske tehnologije je uvek u porastu jer ih pokreće stalno tehničko unapređivanje i povećana svest o čuvanju energije i zaštiti sredine. Razvoj ovakvih tehnologija zasigurno dovodi do smanjenja sagorevanja fosilnih goriva a samim tim i emisije štetnih gasova.

PV/T je hibridna tehnologija koja kombinuje fotonaponsku i solarno-toplotnu tehnologiju u jedan objedinjen sistem zarad povećanja efikasnosti fotonaponskih modula hlađenjem, odnosno odvođenjem toplote od ćelija, a sve uz uštedu prostora na kome se nalaze [4]. PV/T paneli predstavljaju sistem u kome su integrisane prednosti obe tehnologije, odnosno moduli koji su sposobni za istovremenu proizvodnju električne i toplotne energije. Upotrebom PV/T tehnologije dobija se veća iskorišćenost sunčeve energije u poređenju sa konvencionalnim fotonaponskim ili solarnim kolektorima.

2. OSNOVNI PRINCIP, KLASIFIKACIJA I KARAKTERISTIKE PV/T KOLEKTORA

Deo solarnog zračenja (talasne dužine između 0,6 i 0,7 μm) koji padne na površinu PV/T panela apsorbiraju fotonaponske ćelije i pretvaraju se u električnu energiju, dok se preostalo zračenje uglavnom transformiše u obliku toplotne energije [4].

Osnovni delovi svakog ravnog PV/T kolektora su stakleni poklopac, solarne ćelije, kućište i cevni toplotni apsorber (opciono). Toplotni apsorber ima veoma bitnu ulogu u funkciji PV/T sistema. On hladi fotonaponske ćelije i tu energiju koristi za zagrevanje vode ili vazduha. Na ovaj način se povećava stepen korisnosti proizvodnje električne energije.

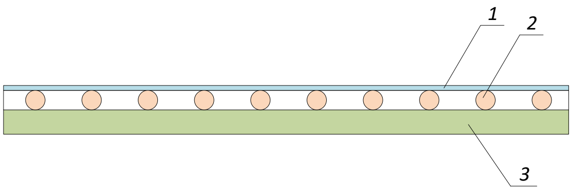


Slika 2. Mreža različitih tehnologija solarnih transformacija [3]

*Kontakt adresa: Fakultet tehničkih nauka Čačak, Svetog Save 32000 Čačak, milan.marjanovic@ftn.kg.ac.rs

U zavisnosti od vrste korišćenog radnog fluida unutar sistema, PV/T kolektori se mogu klasifikovati u sledeće tipove: kolektori koji kao radni fluid koriste tečnost, kombinovani tečnost/vazduh PV/T kolektori i kolektori koji kao radni fluid koriste vazduh. [5]

Kolektori koji su korišćeni za testiranje u okviru laboratorijske postavke su jedan PV/T kolektor i jedan konvencionalni PV (fotonaponski) kolektor. Slika 3 predstavlja skicu poprečnog preseka PV/T kolektora, gde su obeleženi njegovi osnovni elementi: 1-staklena površina kolektora, 2-cevi toplotnog apsorbera, i 3-izolacija.



Slika 3. Poprečni presek testiranog PVT panela

Ukupna efikasnost PVT kolektora je zbir efikasnosti električne konverzije PV panela η_{el} i toplotne efikasnosti solarnog kolektora η_{th}, odnosno:

$$\eta_o = \eta_{th} + \eta_{el} \tag{1}$$

gde su toplotna i električna efikasnost definisani kao količnik korisne toplote odnosno električne energije i sunčevog zračenja koje pada na površinu kolektora.

Prema tome, toplotna efikasnost konvencionalnog ravnog solarnog kolektora je definisana kao odnos korisne prikupljene toplote i ukupne energije sunčevog zračenja.

$$\eta_{th} = \frac{P_{th}}{G} \tag{2}$$

gde je P_{th} korisna dobijena toplotna snaga ravnog toplotnog kolektora, a G ukupna energija solarnog zračenja na površini kolektora. Korisna toplotna se može izračunati kao:

$$P_{th} = \dot{m} c_p \left(T_2 - T_1\right) \tag{3}$$

gde je $\dot{m}$ maseni protok fluida, c_p specifični toplotni kapacitet fluida, , a T_1 i T_2 su ulazna i izlazna temperatura fluida korišćenog za hlađenje, respektivno.

Električna efikasnost η_{el} se može definisati kao:

$$\eta_{el} = \frac{I_m V_m}{AG} \tag{4}$$

gde I_m predstavlja vrednost jačine struje, V_m vrednost napona pri maksimalnoj snazi PV modula, a A - korisna površina testiranog panela.

U nastavku rada prikazane su komponente laboratorijske postavke za merenje toplotne i električne snage PVT panela. Date su osnovne karakteristike korišćenih senzora i opisan korišćeni merno-akvizicioni sistem. Prikazani su i ukratko pojašnjeni rezultati merenja protoka, temperature i snaga. Date su smernice za poboljšanje postojećeg sistema za merenje.

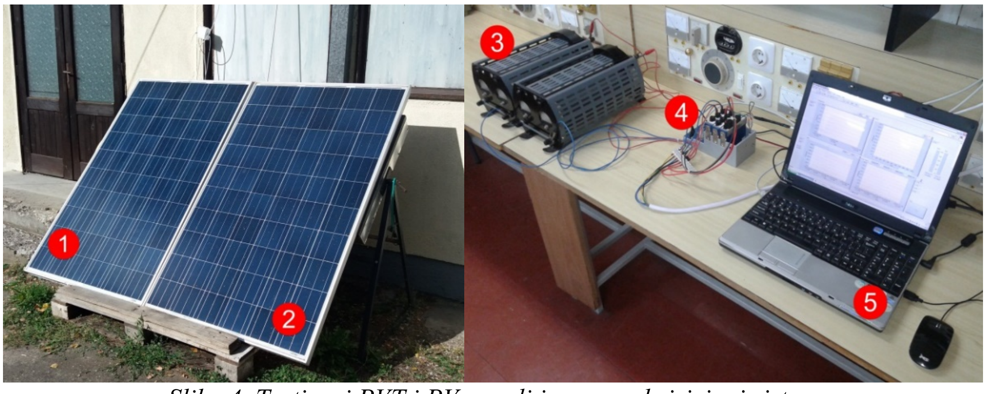
3. LABORATORIJSKA POSTAVKA ZA TESTIRANJE

Na Fakultetu tehničkih nauka u Čačku realizovana je postavka za inicijalna merenja snage fotonaponskih i termičkih modula (slika 4) [6]. Za ispitivanje su korišćena dva identična fotonaponska panela (1 i 2), od kojih je jedan prerađen u PVT panel. PV panel je snage 250 W čije su ćelije izrađene od polikristalnog silicijuma. Paneli su postavljeni jedan pored drugog pod istom elevacijom od 45° i azimutom od 21°. Pri testiranju PVT panela korišćen je otvoren sistem: za probno merenje korišćena je voda iz vodovoda. Blok šema čitavog sistema za testiranje PV i PVT panela prikazana je na slici 5.

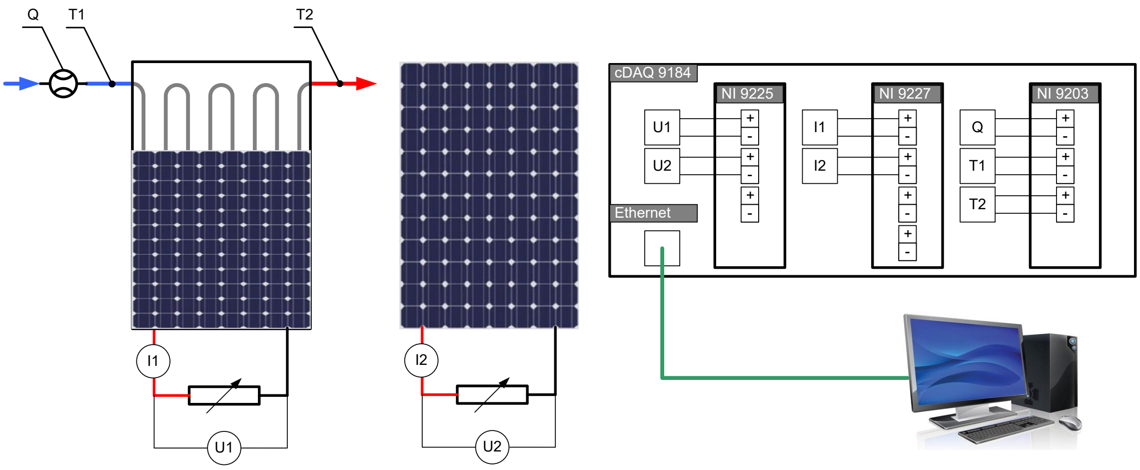
Električno opterećenje oba panela je realizovano promenljivim otpornicima otpornosti 7,5 Ω (Slika 4).

Merenje električne i toplotne snage ostvareno je pomoću odgovarajućih senzora i merno-akvizicionog sistema sa softverom. Merenje jednosmernog napona je obavljeno akvizicionom karticom NI 9225, a struja karticom NI 9227 (Slika 4).

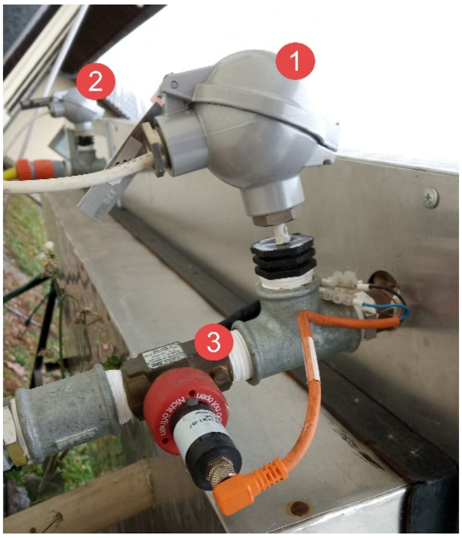
Za indirektno određivanje toplotne snage PVT panela potrebno izmeriti protok i temperature vode na ulazu i izlazu PVT panela. Protok je meren pomoću turbinskog protokomera SIKA VTH 15 MS-41 (slika 6 (3)). Ovaj protokomer može meriti protok vode u opsegu 0–20 litar/min. Na izlazu protokomera se dobija strujni signal u opsegu 4–20 mA, čiji vrednost linearno zavisi od navedenog opsega protoka. Temperatura na ulaznom i izlaznom kraju cevi merena je pomoću termopara tipa T koji u priključnom kućištu ima ugrađen strujni transmiter sa strujnim izlazom u opsegu 4–20 mA. Ovaj strujni opseg linearno zavisi od temperaturnog opsega termopara. Sva tri strujna signala za izmerene temperature i protoka vode kroz PVT panel se dovode na akvizicionu karticu NI 9203. Akvizicione kartice NI 9225, 9227 i 9203 su postavljene na CompactDAQ Ethernet chassis cDAQ 9184 preko koje se vrši snimanje podataka na računaru.



Slika 4. Testirani PVT i PV paneli i merno-akvizicioni sistem
(1 – hibridni PVT solarni panel, 2 – PV solarni panel, 3 – otpornici, 4 – akvizicione kartice, 5 – računar)



Slika 5. Blok dijagram sistema za testiranje



Slika 6. Korišćeni termoparovi (1 i 2) i merač protoka (3)

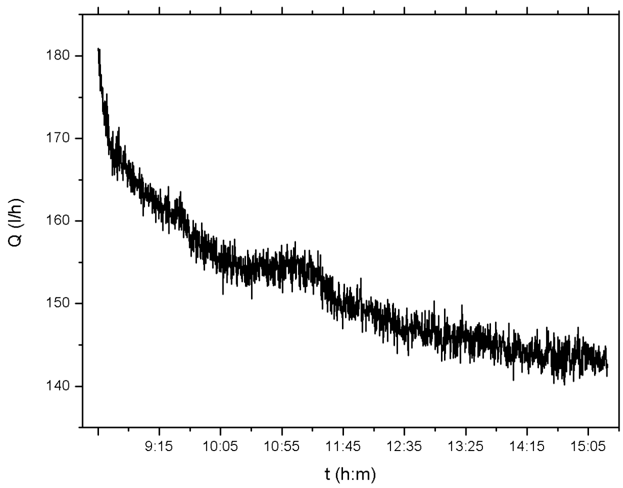
Za obradu i prikaz željenih veličina korišćen je LabVIEW program. Program pruža mogućnost da se izmereni strujni signali prikažu u odgovarajućim veličinama: struja, napon, električna snaga, temperatura, protok, toplotna snaga. Izmerene vrednosti se predstavljaju brojčano i grafički kao funkcija vremena.

4. REZULTATI MERENJA PROTOKA, TEMPERATURA I SNAGA PVT PANELA

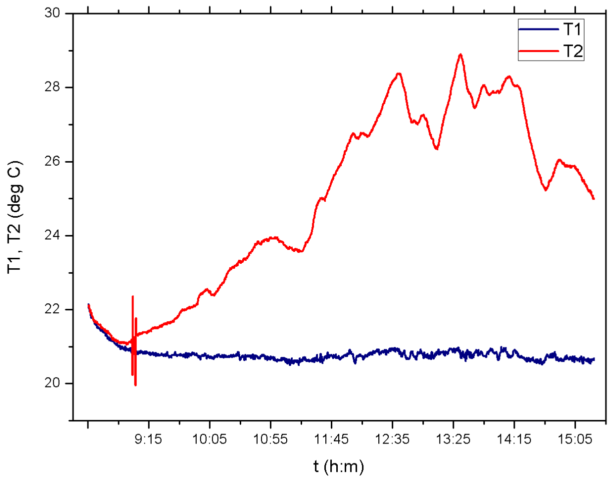
Da bi se odredila toplotna snaga PVT panela potrebno je izmeriti protok i temperaturu vode na ulazu i izlazu krajevima PVT panela. Merenja prikazana u ovom radu su realizovana 18. avgusta 2018. godine u periodu od 8:25 do 15:20 časova. Na slici 7 prikazani su rezultati merenja protoka vode. Primetno je da protok nije bio konstantan tokom čitavog merenja. Na početku je iznosio 180 l/h da bi na kraju merenja iznosio 145 l/h. Srednja vrednost protoka vode za posmatrani period je iznosila oko 150 l/h. Razlog odstupanja vrednosti protoka tokom merenja je promena pritiska vode u vodovodnom sistemu na koji je PVT panel priključen.

Na slici 8 prikazani su rezultati merenja temperature vode na ulazu (T_1) i izlazu (T_2) PVT panela. Na početku merenja temperature su bile identične i iznosile 22°C da bi se zatim snizile za 1°C. Razlog početnog smanjenja temperature vode je dotok hladnije vode iz vodovodnog sistema. Temperatura na ulazu panela se zatim ustaljuje na vrednost od 21°C. Zatim, temperatura vode na izlazu panela počinje postepeno da raste. Izlazna temperatura direktno zavisi od intenziteta sunčevog zračenja. Obzirom na orijentaciju panela, odnosno azimuta intenzitet zračenja se povećavao sa vremenom. Znatne oscilacije u temperaturi su posledica povremenog nailazaka oblaka tokom merenja. Maksimalna temperatura vode na izlazu PVT panela je ostvarena u 13:30 i iznosila je 29°C.

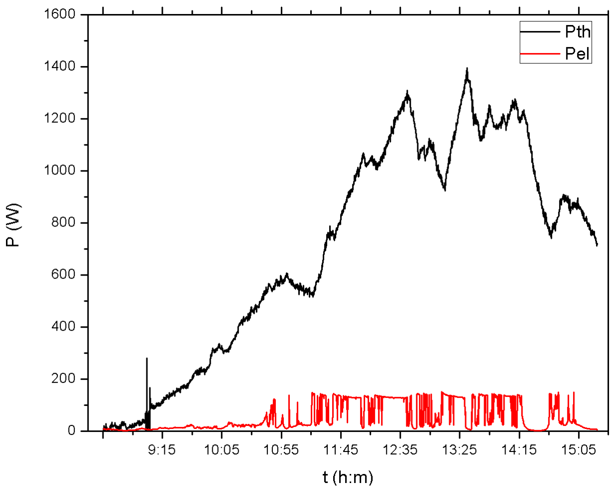
Kao rezultat izmerenih temperatura i protoka dobijene su vrednosti za toplotnu snagu panela. Na slici 9 prikazane su toplotna i električna snaga za posmatrani vremenski period. Obzirom da toplotna snaga direktno zavisi od razlike temperatura (što se može videti iz izraza (3)), dijagram promene snage je po obliku identičan dijagramu promene temperature T_2. Maksimalna toplotna snaga je iznosila 1396 W u 13:30 časova. Dobijena električna snaga koja se predaje otpornicima je znatno manja od toplotne. Takođe, promene električne snage u vremenu su znatno brže u odnosu na promene toplotne snage. Zbog toga su primetne česte oscilacije u električnoj snazi. Promena toplotne snage je znatno inertnija zbog nemogućnosti da se temperatura PVT i vode naglo promeni.



Slika 7. Rezultati merenja protoka vode PVT panela



Slika 8. Izmerene temperature vode na ulazu i izlazu PVT panela



Slika 9. Izmerena toplotna i električna snaga PVT panela

5. MOGUĆNOSTI ZA POBOLJŠANJE PERFORMANSI POSTAVKE ZA TESTIRANJE

Realizovana i testirana oprema za merenje snage PVT panela ima mogućnosti za poboljšavanje svojih performansi. Kada je u pitanju napajanje panela vodom, može se zaključiti da je znatno praktičnije primeniti zatvoreni sistem sa cirkulacionom pumpom. Na taj način je moguće održavanje približno konstantne vrednosti protoka vode, koja se može podesiti na željenu vrednost. Takav sistem bi morao da poseduje izmenjivač toplote kako bi se toplotna energija što efikasnije odvodila. Takođe, primena termoparova koji imaju određenu tačnost (u ovom slučaju ±1°C) bi trebalo zameniti Pt100 senzorima najbolje klase čime bi se znatno povećala tačnost merenja temperature. Naravno, jedina mana korišćenja ovakvih senzora je znatno viša cena.

Što se tiče električne snage, njeno merenje u ovom slučaju ima zadovoljavajuće karakteristike. Međutim korišćenje električnih otpornika ne može obezbediti maksimalnu električnu snagu panela. U ovom delu poboljšanje se može postići korišćenjem invertora koji će obezbediti maksimalnu električnu snagu na izlazu panela za različite intenzitete zračenja sunca.

6. ZAKLJUČAK

Sve veće korišćenje Sunca za proizvodnju električne i toplotne energije zahteva bolje poznavanje PVT panela i njenih karakteristika. Zbog toga je neophodno merenjem odrediti karakteristike panela. Ovaj rad je prikazao jednu eksperimentalnu postavku za određivanje toplotne i električne snage koja se može dobiti sa PVT panela. Takođe, postavka može istovremeno izmeriti i električnu snagu PV panela, kako bi se uporedile njihove karakteristike. Modifikacija PV panela i ugrađivanjem cevi za zagrevanje vode dobija se PVT panel koji može proizvoditi i znatnu količinu toplotne energije. Prikazani rezultati pokazuju izmerene vrednosti temperature i protoka vode PVT panela. Na osnovu tih parametara izračunata je i toplotna snaga PVT panela. Rad je pokazao i određene mogućnosti za poboljšanje postavke kroz promenu tipa senzora za merenje temperatura vode kao i eventualnog korišćenja zatvorenog sistema sa izmenjivačem toplote. Pokazalo se da primena otvorenog sistema napajanja vodom iz vodovodne instalacije bez regulacije protoka dovodi do znatnih promena protoka vode.

ZAHVALNICA

Ovaj rad predstavlja rezultat projekta "Improvement of energy characteristics and quality of the interior space in buildings of educational institutions in Serbia with an impact on health", III 42008, Area: Energy and energy efficiency.

LITERATURA

[1] Athukorala, A., Jayasuriya, W.J.A., Ragulageethan, S., Sirimanna, G., Attalage, R., Perera, A.T.D., "A techno-economic analysis for an integrated solar PV/T system with thermal and electrical storage - Case study", MERCon 2015 - Moratuwa Engineering Research Conference, pp. 182-187, (2015)

[2] "IEA - Key world energy statistics, 2016" http://large.stanford.edu/courses/2017/ph241/kwan1/docs/KeyWorld2016.pdf (accessed 22.12.18)

[3] Zhanga, X., Zhaoa, X., Smitha, S., Xub, J., Yu, J., "Review of R&D progress and practical application of the solar, photovoltaic/thermal (PV/T) technologies", Renewable and Sustainable Energy Reviews 16, pp. 599–617, (2012)

[4] Zondag, H. A., De Vries, D. W., Van Helden, W. G. J., Van Zolingen, R.J.C., and Van Steenhoven, A. A., "The thermal and electrical yield of a PV-Thermal collector", Solar Energy, Vol. 72(2), pp. 113-128, (2002)

[5] Jouhara, H., Szulgowska-Zgrzywa, M., Sayegh, M.A., Milko, J., Danielewicz, J., Nannou, T.K., Lester, S.P., "The performance of a heat pipe based solar PV/T roof collector and its potential contribution in district heating applications", Energy pp. 1-9, (2016)

[6] Šućurović, M., Božić, M., Vujičić, V., Marjanović, M., Dragićević, S., Rosić, M., "Experimental testing of thermal and electrical performance of a hybrid photovoltaic-thermal solar collector", Proceedings of VIII International conference - Industrial Engineering and Evniromental Protection - IIZS 2018, pp.197-203, Zrenjanin, Serbia, 11-12 October, 2018.

IMK-14 – Research & Development in Heavy Machinery 24(2018)4, EN105-108
UDC 621 ISSN 0354-6829

A Laboratory System Development for Measuring Characteristics of Photovoltaic-thermal Panel

Vojislav Vujičić[1], Snežana Dragićević[1], Milan Marjanović[1*], Marko Šućurović[1], Miloš Božić[1], Marko Rosić[1]
[1]Faculty of Technical Sciences Čačak, University of Kragujevac, (Serbia)

The emissions of harmful gases into the atmosphere, air pollution and global warming can be greatly reduced by increasing the use of renewable energy sources such as solar energy to heat domestic hot water, space heating and generating electricity. This paper describes the systems of combined (hybrid) PV/T panels that can simultaneously generate both heat and electricity, as well as the characteristics of the PV/T panel. A prototype of the laboratory setting for the examination of these systems along with the used components is also shown. The temperature, fluid flow rate values, obtained heat and electric gain are also presented. Deficiencies and proposed changes in the laboratory setup and used equipment were laid out, in order to improve the accuracy of the measurements.

Keywords: PVT solar panel, thermal performance, electrical performance, solar energy

1. INTRODUCTION

Increased fossil fuel consumption has led to continuous rising carbon emission to the environment, which has produced about three-quarters of the increase in CO_2 from human activity over the past 20 years. Therefore, there is a need to focus on more environmentally friendly energy sources and conversion technologies to reduce emissions levels and global warming [1].

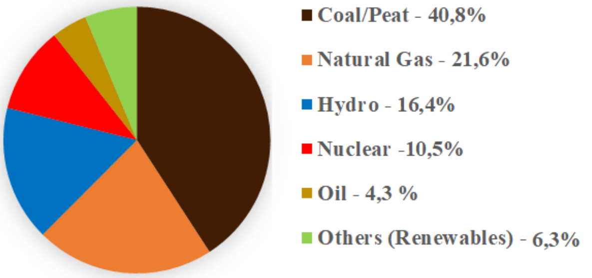


Figure 1. World electricity generation in 2014 (23,816 TWh) by source [2]

Solar energy can be utilized in many ways including solar photovoltaic (PV) panels and solar (thermal) collectors.

Solar thermal can be utilized in various purposes including domestic hot water generation and space heating, solar assisted cooling and industrial process heating. Zhanga et al. (2012) states that it is representing more than 90% of the world-installed solar capacity. It is one of the most cost-effective renewable energy technologies and has huge market potential globally. [3].

The ever-growing use of both solar thermal and PV (photovoltaic) technologies which is driven by the continuous technical improvements and increased concerns of energy saving and environment protection. This development of these technologies would certainly contribute to significant reduction of fossil fuel consumption and carbon emission.

PV/T is a hybrid technology combining PV and solar thermal technology into a single system in order to enhance the solar conversion efficiency of the module by cooling the PV cells and better utilization of space. A PV/T panels can simultaneously generate electricity and heat, and therefore represent a system in which are integrated advantages of both PV and solar thermal technologies. The use of PV/T technology result in a greater overall conversion rate of the Sun energy compared to a conventional PV or solar thermal collector, thus enabling more efficient use of solar energy.

2. BASIC PRINCIPLE, CLASSIFICATION AND PERFORMANCE OF PV/T COLLECTORS

A part of the solar irradiation (within the wavelength from 0.6 to 0.7 μm) that falls on the PV/T panel's absorbing surface is absorbed by the PV cells and converted into electricity, while the remaining irradiation is mostly transformed in the form of thermal energy [3].

The basic parts of every flat plate PV/T collector are a glass cover (glazed or unglazed), solar cells, encapsulated materials and the absorber collector (optional). The collectors' absorber has a significant function in the PV/T system; it cools down the PV cell and uses the waste thermal energy to produce hot water or hot air. In this way the efficiency of the PV module increases significantly [4].

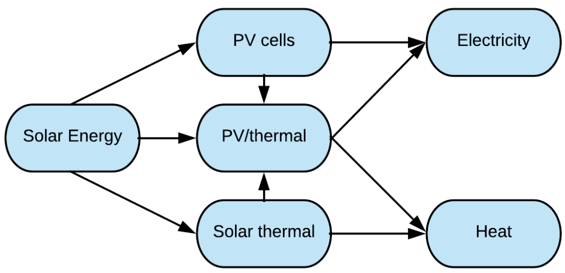


Figure 2. Network of different solar conversion technologies [3]

Flat plate PV/T collectors can be classified into the following categories, depending on the type of working fluid used: water PV/T collectors, combined water/air PV/T collectors and air PV/T collectors. [3]

The collectors used for testing within the laboratory setup are one PV/T and one conventional PV collector. A Figure 3 represents a cross section of a PV/T collector, in

*Corresponding author: Faculty of Technical Sciences Čačak, Svetog Save 32000 Čačak, milan.marjanovic@ftn.kg.ac.rs

which its basic elements are numbered: 1-collectors glass surface, 2-heat absorber pipes, and 3-insulation.

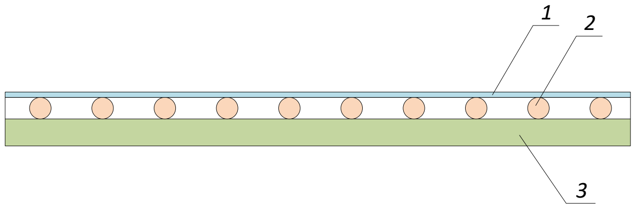


Figure 3. A cross section of a used PV/T panel

The total efficiency of a PV/T collector is sum of the electrical efficiency η_{el} and the thermal efficiency η_{th}, or as follows:

$$\eta_o = \eta_{th} + \eta_{el} \tag{1}$$

Where thermal and electrical efficiency are defined as the ratios of gained heat an electricity to the irradiation that falls on the surface area of the collector's plate [5].

Therefore, the thermal efficiency of the steady state conventional flat plate solar collector is defined as the ratio of useful heat collected to the total energy:

$$\eta_{th} = \frac{P_{th}}{G} \tag{2}$$

where P_{th} is useful heat gain of a flat-plate thermal collector, and G is a total solar radiation on a collector's surface. Useful heat gain is available as:

$$P_{th} = \dot{m} c_p \left(T_2 - T_1\right) \tag{3}$$

where $\dot{m}$ is the mass flow rate of heat transfer fluid, c_p is the specific heat of the transfer fluid, and T_1 and T_2 are the outlet and inlet cooling fluid temperatures, respectively.

The electrical efficiency η_{el} can be defined as:

$$\eta_{el} = \frac{I_m V_m}{AG} \tag{4}$$

where I_m is the value of current, A is the aperture area of the tested system, and V_m is voltage at the maximum power point of PV module operation.

Laboratory components for measuring the heat and power of the PV/T panel are presented further in the paper. The basic characteristics of the used sensors are described as well as the used measurement and acquisition system. The results of the measurement of flow, temperature and power are briefly explained, and guidelines for improving the existing measurement system are also given.

3. LABORATORY TEST SETUP

An initial laboratory test setup for measuring the heat and electrical gain of the thermal and PV panels is realized at the Faculty of Technical Sciences Čačak (Figure 4) [6]. A two identical PV panels of which one is upgraded to PV/T panel, are used for testing (1 and 2, Figure 4). PV panels are rated at 250 watts of electrical power, whose cells are made from polycrystalline silicon. They are placed next to each other at the exact same angle elevation of 45° and azimuth of 21°. A water from the water supply is used as a transfer fluid for PV/T panel test measuring which is an open system. Block diagram of the testing system for PV and PVT panels are shown in Figure 5.

The electrical load of both panels is realized by variable resistance resistors with resistance of 7,5 Ω (Figure 4).

A measurement of electrical and thermal power was achieved by using the appropriate sensors and data acquisition system with corresponding software. The DC voltage and current measurements were collected with the acquisition cards NI 9225 and NI 9227 respectively (Figure 4).

In order to determine the thermal power of the PV/T panel indirectly, it is necessary to measure the flow rate and the inlet an outlet water temperature of the panels. The flow rate was measured using a turbine flowmeter SIKA VTH 15 MS-41 (Figure 6 (3)). The measuring range of a used flow rate meter is 0-20 liters/min. The output of the sensor is a current signal from 4 to 20 mA which is in linear dependence on the specified flow rate through the panel. At the inlet and outlet pipes, two type T thermocouples are placed for measuring temperatures. A built-in current transmitter with a current output in the range of 4-20mA is in the thermocouples terminal box. This current range is linearly dependent on the temperature range of the thermocouples. All three mentioned signals of the measured temperatures and flow rate are connected to the NI 9203 acquisition card. NI 9225, 9227 and 9203 acquisition cards are places on a CompactDAQ Ethernet chassis cDAQ 9184 through which data is collected on a computer.

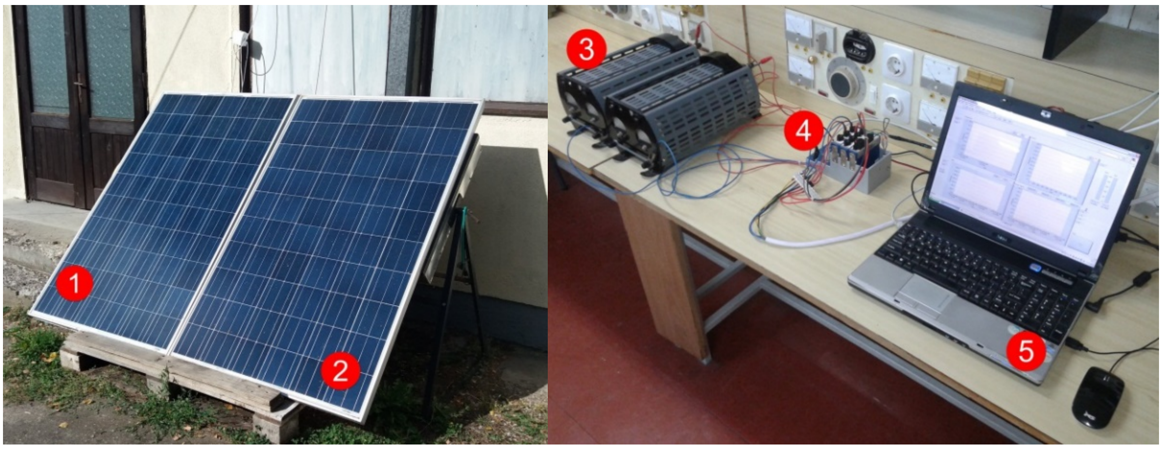


Figure 4. Testing PVT and PV panels and data acquisition system
(1 – hybrid PVT solar collector, 2 – PV solar collector, 3 – resistors, 4 - acquisition cards, 5 – computer)

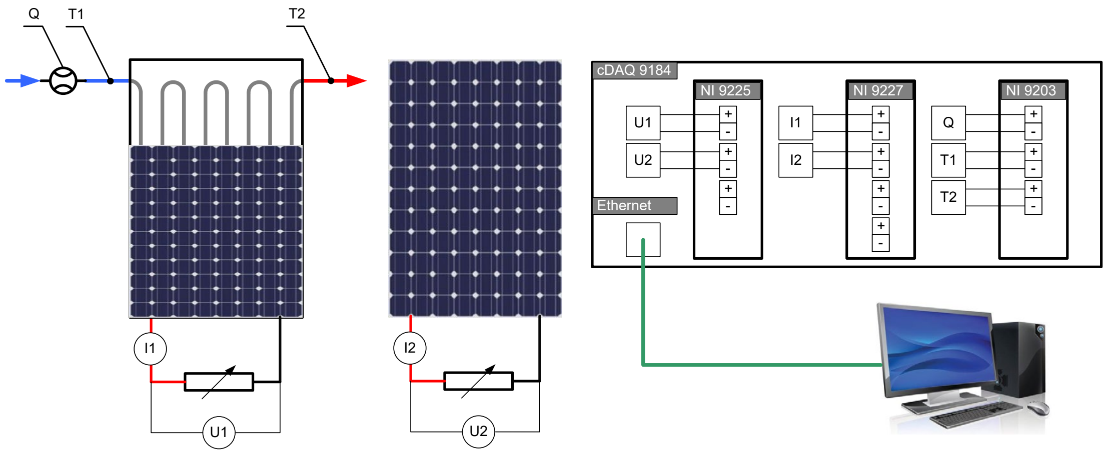


Figure 5. Block diagram of the testing system

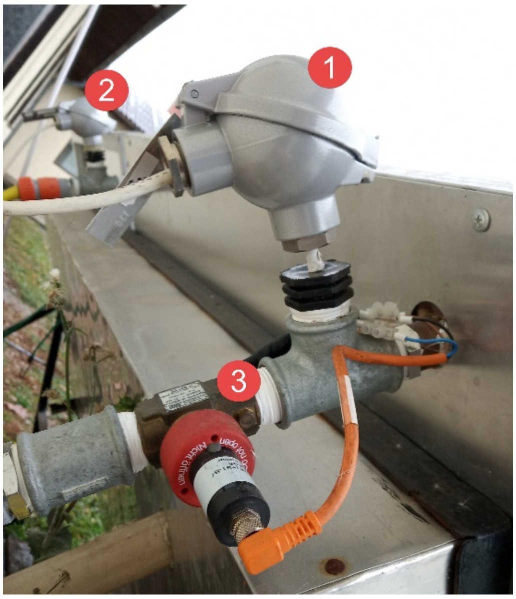


Figure 6. Used thermocouples (1 and 2) and flowmeter (3)

A LabVIEW software was used to process and display the measured values. The software provides the ability to display measured signals as current, voltage, electrical power, temperature, flow rate, thermal power. Measured values are represented numerically and graphically as a function of time.

4. RESULTS OF THE MEASURED FLOW, TEMPERATURE AND POWER OF THE PV/T PANEL

In order to determine the thermal power of the PV/T panel, it is necessary to measure the flow and inlet and outlet temperatures of the PVT panel. The measurements shown in this paper were carried out on August 18, 2018 in the period from 8:25 to 15:20. A figure 7 shows the results of water flow measurement. It is can be seen that the flow rate was not constant throughout the measurement. Initially, it was measured at 180 l/h and at the end of measurement it reached value of 145 l/h. A mean water flow rate for the observed period was around 150 l/h. The reason for the deviation of the flow value during the measurement period is the change of water pressure in the water supply system to which the PV/T panel was connected directly.

A figure 8 shows measured water temperatures at the input (T_1) and the output (T_2) of the PVT panel.

At the beginning of the measurement, the temperatures were identical at the value of 22 °C, then they were decreased by 1 °C The reason for the initial decrease in water temperature is the inflow of the cooler water from the water supply system. After that, the inlet water temperature then settles to a value of 21 °C. Then, the outlet water temperature starts to gradually increase. Outlet temperature directly depends on the intensity of the solar irradiation. Considering the orientation of the panel, azimuth, the intensity of irradiation was increasing with time. Occasional clouds results in significant oscillations in temperature. A maximal outlet water temperature is achieved in 13:30 at the value of 29°C.

A thermal power of a PV/T is determined as a result of measured temperatures and flow rate of water. Calculated thermal (P_{th}) and electrical power (P_{el}) are shown in the figure 9. Since the heat power directly depends on the temperature difference (as can be seen in formula 3), and the inlet temperature T_1 is held fairly constant, the thermal power diagram is shaped identically as the temperature diagram T_2. The maximum heat output was 1396 W at 13:30 (3). The electrical power delivered to the resistors has considerably lower value than the thermal power. Also, the electrical power value changes much faster than the thermal power. This is the reason why frequent oscillations in electrical power are noticeable. The change in thermal power is significantly more inert due to the heat capacity of the materials through which the heat is conducted.

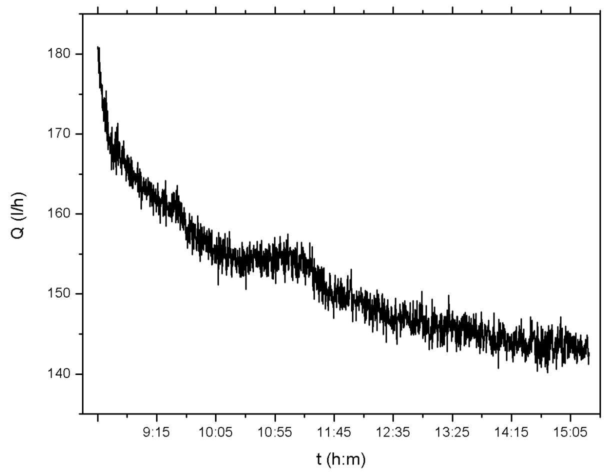


Figure 7. Flow rate measured values of the PV/T

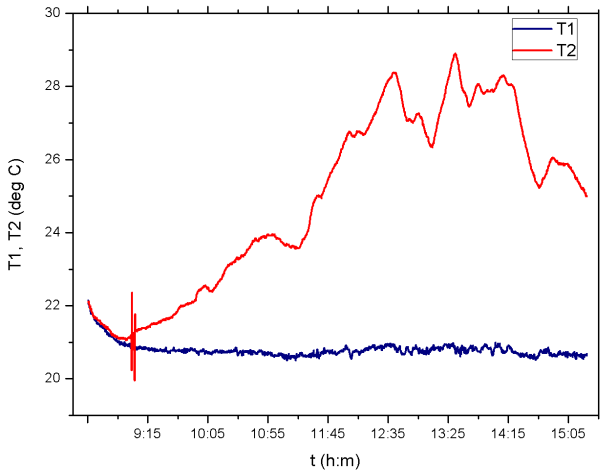


Figure 8. Inlet (T_1) and outlet (T_2) water temperature of the PV/T

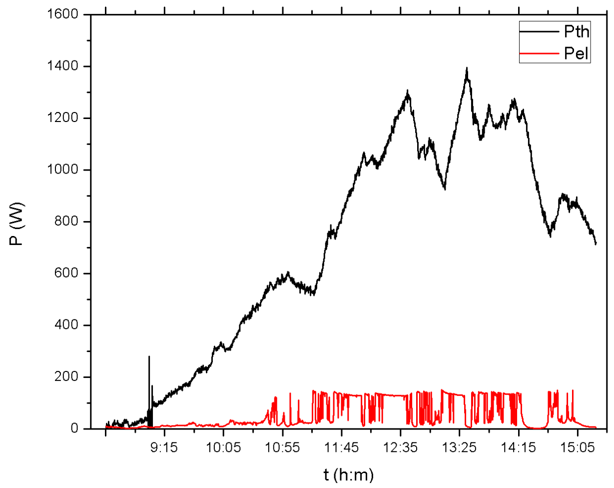


Figure 9. Determined heat and electrical power of the PV/T

5. POSSIBILITIES FOR IMPROVING THE PERFORMANCE OF THE TEST SETUP

This test setup for obtaining the power of PV/T system has the ability to improve its performance. Then it comes to the used fluid from the water supply, the more convenient solution is to apply a closed circulation pump system. This way a water flow rate can be held at constant value, and can be changed to desired value easily. Such system should have a heat exchanger in order to make the heat energy transfer more efficient. In addition, to increase the accuracy of the temperature measurement, the use of thermocouples having a certain accuracy (in this case ± 1°C) should be replaced by the Pt100 sensors. Of course, the only drawback to using such sensors is a significantly higher price.

As far as the electrical power is concerned, the accuracy of the measurement in this case is satisfactory. However, the use of electrical resistors cannot provide the maximum electrical power of the panel. This part can be improved by using an inverter that will provide maximum electrical power at the output of the panel for different sun irradiation intensity.

6. CONCLUSION

Increasing the utilization of the Sun's energy for production of electricity and heat requires a better knowledge of PV/T panels and its characteristics. Therefore, it is highly necessary to determine the characteristics of the panel. This work presents an experimental setup for determining the heat and electrical power that can be generated from the PV/T panel. In addition, this setup is capable of measuring the electrical power of an identical PV panel at the same time, which gives opportunity to compare their electrical characteristics. Modification of PV panel and incorporation of heat pipes provide a PV/T panel that can produce a significant amount of heat. The results shown in this paper are the measured values of the temperature and water flow of the PVT panel, based on which the thermal power of the PV/T is calculated. Also, the possibilities for improving the setup by changing the type of sensor for measuring the water temperature as well as the possible use of a closed system with a heat exchanger are also presented in this paper. It has been shown that the use of an open water supply without flow regulation can lead to significant changes in the flow rate.

ACKNOWLEDGEMENTS

This paper presents the result of the project "Improvement of energy characteristics and quality of the interior space in buildings of educational institutions in Serbia with an impact on health", III 42008, Area: Energy and energy efficiency.

REFERENCES

[1] Athukorala, A., Jayasuriya, W.J.A., Ragulageethan, S., Sirimanna, G., Attalage, R., Perera, A.T.D., “A techno-economic analysis for an integrated solar PV/T system with thermal and electrical storage - Case study”, MERCon 2015 - Moratuwa Engineering Research Conference, pp. 182-187, (2015)

[2] "IEA - Key world energy statistics, 2016" http://large.stanford.edu/courses/2017/ph241/kwan1/docs/KeyWorld2016.pdf (accessed 22.12.18)

[3] Zhanga, X., Zhaoa, X., Smitha, S., Xub, J., Yu, J., “Review of R&D progress and practical application of the solar, photovoltaic/thermal (PV/T) technologies”, Renewable and Sustainable Energy Reviews 16, pp. 599–617, (2012)

[4] Zondag, H. A., De Vries, D. W., Van Helden, W. G. J., Van Zolingen, R.J.C., and Van Steenhoven, A. A., “The thermal and electrical yield of a PV-Thermal collector”, Solar Energy, Vol. 72(2), pp. 113-128, (2002)

[5] Jouhara, H., Szulgowska-Zgrzywa, M., Sayegh, M.A., Milko, J., Danielewicz, J., Nannou, T.K., Lester, S.P., “The performance of a heat pipe based solar PV/T roof collector and its potential contribution in district heating applications”, Energy pp. 1-9, (2016)

[6] Šućurović, M., Božić, M., Vujičić, V., Marjanović, M., Dragićević, S., Rosić, M., “Experimental testing of thermal and electrical performance of a hybrid photovoltaic-thermal solar collector”, Proceedings of VIII International conference - Industrial Engineering and Evniromental Protection - IIZS 2018, pp.197-203, Zrenjanin, Serbia, 11-12 October, 2018.