

## MEASUREMENT SYSTEM FOR RESEARCH ON PHOTOVOLTAIC THERMAL (PV/T) LIQUID BASED SOLAR COLLECTOR

Viktor Šunde, Mario Vražić and Damir Ilić

University of Zagreb Faculty of Electrical Engineering and Computing (FER)  
 Unska 3, HR-10000 Zagreb, Croatia; tel. +385 1 6129 770, fax. +385 1 6129 705  
[mario.vrazic@fer.hr](mailto:mario.vrazic@fer.hr)

**Abstract:** This paper describes the design of measurement system that will be installed on photovoltaic thermal (PV/T) liquid based solar collector. General idea of this research is to optimize total efficiency of such PV/T panel. That means balancing between the amount of produced electrical energy and thermal energy. In order to even start such research, one should design a robust measurement system that could provide necessary support in measurement.

**Keywords:** measurements system, photovoltaic thermal (PV/T) liquid based solar collector

### 1. INTRODUCTION

Nowadays, due to several different factors, renewable energy is highly valued. That specially refers to solar energy used to produce thermal and electrical energy.

Those two forms of energy can be exploited together with photovoltaic thermal (PV/T) liquid based solar collector. There photovoltaic panel is combined with thermal solar collector. It is known that photovoltaic panel reduces efficiency with temperature raise.

Therefore it would be more efficient if it is cooled. And the two most common ways are the use of cooling liquid or air. Liquid takes thermal energy, its temperature raises, so it can be used in households and industry as warm liquid. Liquid can be additionally heated in a boiler, but with significantly lower electrical energy consumption than for normal tap liquid.

The main issue for PV/T is optimisation of temperatures. So the liquid flow should be controlled with photovoltaic efficiency as feedback. In that way photovoltaic operates at its highest efficiency for that operating point. In order to obtain all relevant parameters one should design proper measurement system to back up such research.

Since PV/T must be placed outside, most parts of measurement system should be with IP65 protection and capable for very high (up to 70 °C) and very low (down to -25 °C) temperatures. Such and all other necessary considerations in measurement system design should be taken into consideration.

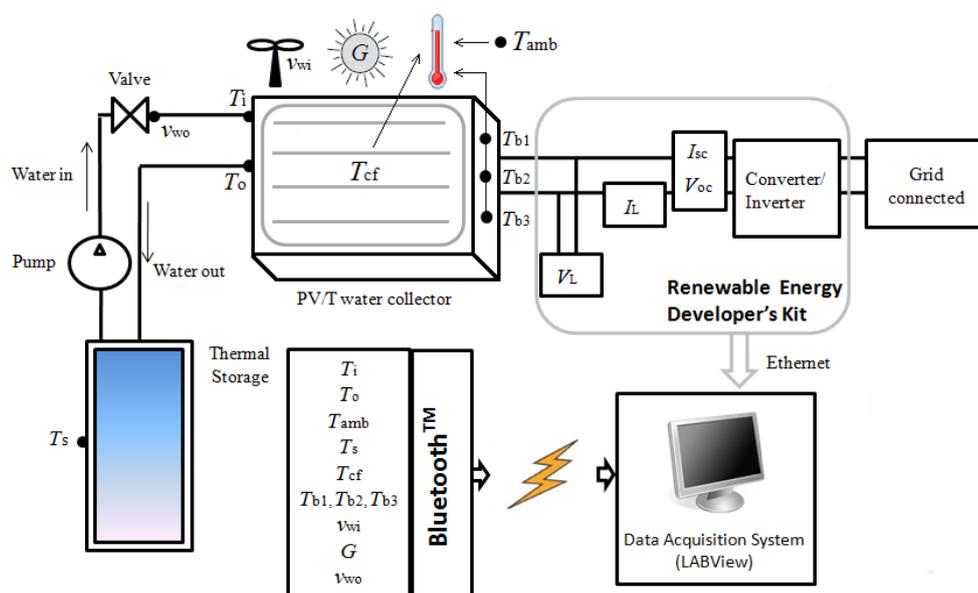


Figure 1. Schematic diagram of simulation model of PV/T liquid based system

## 2. MEASUREMENT SYSTEM

### A. Measured values

To achieve the experiment goals with the proposed simulation model of PV/T system, it is necessary to measure the following values during the experiment (Figure 1.):

- inlet liquid temperature ( $T_i$ )
- outlet liquid temperature ( $T_o$ )
- ambient temperature ( $T_{amb}$ )
- thermal storage temperature ( $T_s$ )
- solar cell temperature
  - o front side ( $T_{cf}$ )
  - o back side ( $T_{b1}, T_{b2}, T_{b3}$ )
- wind velocity ( $v_{wi}$ )
- solar intensity ( $G$ )
- liquid velocity ( $v_{wo}$ ) or liquid flow
- load current ( $I_L$ ) and load voltage ( $V_L$ )
- short circuit current ( $I_{sc}$ ) and open circuit voltage ( $V_{oc}$ )

### B. Measuring equipment

Several devices are going to be used to take measurements and characterize the performance of PV/T system, including seven digital thermo probes, anemometer, a pyranometer and a device for measuring the flow. For measuring of the voltage and current the facilities provided by the Renewable Energy Developer's Kit development circuit board are used. To measure the surface temperature of the photovoltaic panel a thermal camera will also be used.

In order to characterize the thermal performance of PV/T system, temperature measurements have to be taken at various locations throughout the assembly. For measuring the temperature digital thermo probes DS18B20 of accuracy  $\pm 0,5$  °C are selected.

One digital thermo probe will be mounted on the outside surface (away from PV/T module) to measure ambient temperature ( $T_{amb}$ ). One thermo probe will be used to measure solar cell temperature ( $T_{cf}$ ). Three thermo probes will be embedded between the PV panel and the solar absorber measured interior panel temperature or back side cell temperature ( $T_{b1}, T_{b2}, T_{b3}$ ). With three digital thermo probes the temperatures of the cooling medium at entry into the solar collector ( $T_i$ ), at exit from the collector ( $T_o$ ) and temperature of the cooling medium in the heat tank ( $T_s$ ) are measured.

For calculation of the thermal efficiency and electrical efficiency it is necessary, in addition to the temperature, to measure the mass flow of the cooling medium and irradiation. The coolant flow rate through the solar collector, which varies from (0,01 to 0,03) kg/s per square meter of collector, will be measured with ultrasonic flow and heat meter. The insolation measurements will be

taken by a pyranometer (Kipp&Zonnen - CM21) mounted in the same plane as the panel.

Forming the remainder of the data collection suite is anemometer. It is important to collect wind speed and direction measurements to determine how wind will influence the efficiency of the panel. An anemometer (P-670-M) with two mini probes will be mounted on the exterior of the assembly, to measure the wind speed.

Mass flow of the cooling medium, irradiation and wind speed change slowly. Neither the voltage nor the current have to be sampled very frequently, so a cheaper acquisition system can be used, that should have at least 14 bit A/D conversion, for accuracy.

For capture of digital data from the thermal probes and analogue values from the anemometer, pyranometer and devices for measuring the flow, a special measuring system was developed, Figure 2 [10]. The temperature signals and signals of other physical values are converted into the digital ones, which are sent to the computer in packages, via wireless communication. The measuring system is intended as a universal dislocated platform for which the operational principle and the operating algorithm can be remotely changed.

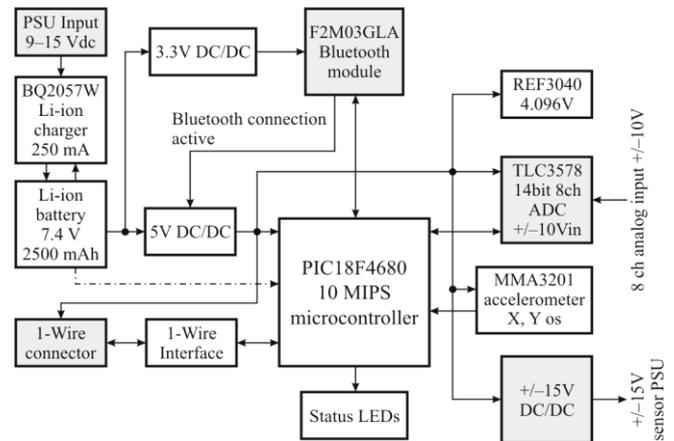


Figure 2. Measuring system block diagram

The measuring system consists of several parts:

- Bluetooth communication module
- microcontroller
- 14-bit ADC
- Li-ion battery

For wireless communications media Bluetooth™ is selected for its simplicity of use, high data transfer speed, low power consumption, and for safety of the data flow (additional safeguards to protect the correctness of the packages are not required).

The heart of the measurement system is PIC18F460 microcontroller which routes data from the sensors to the

Bluetooth interface. Each thermo sensor DS18B20 has a unique 64-bit serial code, which allows multiple DS18B20 to function on the same 1-wire bus. Routines for searching, addressing and reading 1-wire temperature sensors are integrated in the embedded code of the microcontroller.

The measuring system uses 14-bit 8-channel analogue-digital converter connected to the microcontroller via a synchronous serial SPI (Serial Peripheral Interface) interface. The analogue-digital converter has the input voltage range of  $\pm 10$  V and the maximal sampling rate of 200000 samples per second. Anemometer, pyranometer and cooling medium flow meter are connected to the analogue-digital converter.

Three DC/DC convertors are built into the measuring system since several powering voltages are needed (3,3 V, 5 V, 15 V, -15 V). The 3,3 V converter is permanently switched on and powers only the Bluetooth™ module, while the other convertors are switched on when the successful Bluetooth™ connection is established. When other convertors are switched on, the microcontroller is also switched on and the system is then ready for work.

Bluetooth module F2M03GLA is connected to the microcontroller via an USART interface, so the system acts as a virtual serial port on the host computer. A protocol for communication between the PC host and the measurement system was also developed.

The values of voltage and current of the photovoltaic collector, as well as the values of voltage and current on the exit of the inverter obtained by a Texas Instruments development circuit board, are connected to the host computer via Ethernet.

The data from all of the sensors have to be monitored and logged on to the host computer. The application for the graphical user interface was developed in the National Instruments programming language LabVIEW. The GUI application sends commands to the measurement system over the Bluetooth virtual serial port and waits for its response. The time base of the measurement is generated by the host system. The application searches for sensors and monitors the temperature and other measured values. Monitored values of each sensor together with time base are logged in a textual file which is used for further analysis. Minimum sampling period is limited with the resolution of sensors.

#### 4. PREPARATIONS

So far an idea of the whole PVT model was presented. But there are lots of problems and decisions in application of such idea.

First of all, cooling media should be resistant to great heat (up to 100°C) and also resistant to freezing (down to -30°C). Therefore the same liquid as in internal

combustion engines should be used as cooling liquid. All of its properties are suitable for this purpose.

Since here is the case of research, there is an idea to produce PVT ourselves. So, at first, there was idea to use a radiator made from copper. But copper is expensive so the decision was made to use aluminium instead. Therefore an aluminium tubes and aluminium plate as absorber were bought and the radiator was made from them, Fig. 3, and Fig. 4.



Figure 3. Aluminium tubes mounted on back side of PV module



Figure 4. Aluminium plate as absorber mounted on back side of PV module

Since aluminium is hard to weld, there were lots of problems with leakage. PVT is very heavy and PV frame can not support such weight. So additional frame was designed and built. Next problem was to build a test stand for PVT. The demands on the test stand were that it should be flexible. It should be easily movable so it is on the wheels (Fig. 5).



Figure 5. The mobile stand for the whole model

The whole measurement system, except *Renewable Energy Developer's Kit (REDK)* is set on the stand. The idea is that everything is mobile but PC and DC link to power converter. The model could be transported anywhere in two parts (stand with everything described on it and REDK with PC) and then connected to power grid. Stand is, of course, capable for all weather conditions while REDK and PC have to be placed indoors. The Figure 6 shows the entire PV/T setup. After completing a model of PV/T we will begin with the experiments on the setup using the proposed measurement system.



Figure 6. The entire PV/T setup

### 3. CONCLUSION

This concept is designed to enable testing on different locations thus enabling more research capabilities. It can be used for indoor research by using steady source of light and heat such as light reflectors. In such operation, research on cooling liquid and its efficiency can be done, as well as the research on the whole cooling system. Of course, in such conditions, model itself can also be tested.

When used outdoors, with previous indoor calibration, this model could also be used for research of particular place on Earth and its capabilities for heat and electric energy production due to Sun insolation.

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