PV-T Test Bench Based on Arduino

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ABSTRACT: Photovoltaic thermal collectors, commonly abbreviated as PVT collectors and also known as hybrid solar collectors, photovoltaic solar collectors, PV / T collectors or solar cogeneration systems, are power generation technologies that transform solar radiation into usable thermal and electric energy. The development of a test bench for a Photovoltaic Thermal Panel (PV-T) is presented in this work. A PV-T panel was designed and a test bench needed to obtain experimental data for thermal and electrical modelling. A self-developed Open Source system based on Arduino platform is used to acquire data from the various sensors and actuators on the test bench. The system is implemented in the municipality of Marín, Pontevedra province (Spain). The parameters to be controlled and the chosen instrumentation as well as the Arduino-based device operation are explained in this paper. Finally, it provides a summary of the experimental results collected.

KEYWORDS: PV-T test bench, Arduino, Open Source data acquisition, Solar, Photo voltaic, Thermal energy.

INTRODUCTION

As solar energy technologies have advanced in recent years, integrated solar energy harvesting technologies in building sectors such as Building-Integrated Photovoltaic (BIPV) Systems, Building-Integrated Solar Thermal (BIST) Systems or Building-Integrated Photovoltaic/Thermal (BIPVT) Systems have evolved as viable technologies for improving energy efficiency in building and reducing environment. These integrated systems replace parts of conventional building materials and components in the buildings' climate envelope, such as facades and roofs, and simultaneously serve as building envelopes for materials and power generators [1].

Today, most production photovoltaic (PV) modules are based on crystalline silicon wafer technologies. The electricity conversion efficiency of the commercially available silicon solar modules is approximately 12–20%. However, the incoming solar energy is either reflected or absorbed as heat energy by more than 85 per cent. Consequently, after extended operations the working temperature of the solar cells increases considerably. Solar panel temperature is one of the main factors influencing the efficiency of electricity production, most solar cells display a heat-related output loss of approximately 0.4–0.5 per cent / C. Without a cooling device, surface temperatures in-service are usually 40–50 C above ambient temperature, resulting in 16–25% reductions in electricity production or failure beyond the operating temperature range [2]. The increase in PV temperature not only reduces the generation of electricity but also the life span of the module itself.

Thus, a technique capable of cooling the solar panel is in high demand to increase both the energy efficiency and the service life of the solar panels. If a BIPV system is properly built, the cooling load of the building envelope in which PV modules are installed can be removed and the heat energy can be stored by the flow of air or a liquid, this is the basic principle of a BIPVT system design. The BIPVT device appears as groundbreaking new technology as it fuses photovoltaic and thermal systems, capturing both electrical and thermal energy simultaneously. The most popular BIPVT systems are realized in an open-loop (usually air) or closed-loop (usually liquid) configuration by means of a heat transfer fluid [3].

An author engineered a BIPVT open-loop air-based system, which was thermally coupled with a ventilated concrete slab. Their field test results indicated that a standard efficiency for thermal energy collection of about 20 percent could be achieved, and as a result the house's annual space heating energy consumption is about 1600 kW h, which is about 5 percent of the national average. In a full-scale solar simulator a prototype open loop air-based BIPVT system with one single inlet was experimentally studied. It was found that the temperature of PV arrays would rise to high values (over 70 C) in an open-loop air-cooled BIPVT system with large-scale PV areas covering complete roof or facade surfaces, resulting in a substantial reduction in the electrical efficiency and degradation of PV panels over time.

Therefore it is beneficial to increase heat removal from the PV panels by using multiple inlets rather than a single inlet. They further developed a two-inlet BIPVT system for this purpose. Their test results indicated that, compared to a conventional one-inlet system, an equivalent two-inlet system with frameless PV panels can increase thermal efficiency by 5 percent. Considering the high thermo-physical properties of liquid relative to air, closed-loop configuration with liquid is typically more efficient than open-loop with air as a heat transfer fluid. Based on the closed loop configuration, Corbin engineered a BIPVT with thermal and combined (thermal plus electrical) efficiencies of around 19 per cent and 34.9 per cent, respectively, within the category of rooftop or roof added BIPVT systems. Their test results showed that their BIPVT photovoltaic output could be improved by 5.3 per cent and that the warm water obtained was appropriate for domestic use. A BIPVT roofing device with a copper spiral flow absorber mounted to the roof at the bottom of the PV modules [4].

It was recorded that for a BIPVT system recently established a BIPVT roof collector combined with a liquid desiccant enhanced indirect evaporative cooling system, an energy efficiency of about 55–62 per cent can be achieved. Their experimental findings showed that the BIPVT roof collector is capable of delivering approximately 3 kW of heating, 5.2 kW of cooling power and 10.3 MW h / year of generating power. Moreover, the overall power efficiency data also shows that the power energy output of PV modules can be improved by 10.7% due to collector cooling, because the cold water flow produces a passive cooling effect and partially eliminates the waste heat from the PV modules. Most closed-loop BIPVT systems currently use water tubes for cooling and for the collection of thermal energy.

The water tubes are usually coated in insulating materials and protected by the absorber materials in contact with the above PV components. Because of the limited contact area between the absorber and water pipes, these designs usually experience poor heat conduction. A recent study has shown that the development of a BIPVT roofing panel with functionally graded materials (FGMs) as a key component has great potential to harvest solar energy efficiently. The proposed FGM layer has the intention of acting as a lightweight layer of a solar roofing panel with varying thermal conductivity in the direction of thickness. For many years now our research group has been committed to understanding this special BIPVT technology [5].

Originally, a hybrid solar panel installed with PV cells and thermoelectric (TE) modules was developed to produce both electricity and warm water, but eventually it was found that the incorporation of the TE modules could not provide any advantages over PV cells by itself. The TE modules were subsequently omitted and the BIPVT heat transfer and overall performance were simulated and measured, respectively. Notice that in the original design, the solar panel was limited to a small size (304.8 mm / 304.8 mm) obstructed by the FGM panel manufacturing process, which was produced by simply placing mixed powders with varying mixing ratios of HDPE and Al particles into various layers to form a multi-layer composite sheet.

Photovoltaic-thermal panels (PV-T) are systems which combine photovoltaic technology with thermal power generation. Air-cooled PV-T panels are simpler to implement, so liquid-cooled circuits are not required. Instead, they claim the immediate use of the generated hot air. Many of these systems' uses are: space heating, clothing, and food drying etc. The configuration of the proposed PV-T panel suits the needs of campaign users (military or not), where there are restricted sources of thermal and electrical energy. The panel is based on thin-film and aims to provide a compact, portable, and lightweight prototype that can be used to provide hot air and electricity in isolated areas. The system is developed using decision-making techniques with multi-criteria which lead to a design solution. A test bench is designed and developed to obtain experimental data to assess the performance of the PV-T system. These experimental data will later be used to validate proposed models built in various computer software.

LITERATURE REVIEW

Photovoltaic and solar thermal power generation dominated the conversion of the sunlight into electricity. Photovoltaic cells are commonly installed, often as flat panels, whereas the generation of solar thermal electricity, depending on optical concentrators and mechanical heat engines, is only seen in large power plants. Here we demonstrate a promising flat-panel solar thermal conversion technology to electric power conversion based on the Seebeck effect and high thermal concentration, allowing wider applications. Under AM1.5 G (1kW m-2) conditions, the solar thermoelectric generators (STEGs) produced achieved a peak efficiency of 4.6 per cent [1]. This paper presents a review of different methods that can be used to minimize the negative impacts of the raised temperature while attempting to increase the efficiency of photovoltaic solar panels operating beyond the recommended standard test conditions (STC) temperature. Different cooling technologies are checked, namely Floating Tracking Concentrating Cooling Cell (FTCC); Hybrid Solar Photovoltaic/Thermal Cell Cooled by Water Sprinkling; Hybrid Solar Photovoltaic/ Thermoelectric PV/TE System Cooled by Heat sink; Hybrid Solar Photovoltaic / Thermal (PV / T) Cooled by Forced Water Circulation; Improved performance of solar panels by using phase-change systems [2].

This analysis paper will help to identify new cooling methods, different thermal absorber design and various phase-change materials to boost photovoltaic performance. From the literature it has been observed that photovoltaic panel with phase change material (PV-PCM) is a proficient solution for photovoltaic panel cooling. However, the problems associated with phase change material are its low thermal conductivity and nocturnal solidification, which affects its readiness and thermal drop performance for the same day and the following day, so photovoltaic panel performance with phase change material (PV-PCM) system can be enhanced by inserting heat transfer elements into PCM and extracting heat from PCM to regulate temperature. This article presented experimental investigation of different PV systems under environmental conditions to improve performance of PV panel. The convectional PV panel, water based photovoltaic/thermal system (PV/T) with double absorber plate and water based photovoltaic/thermal system with phase change material (PCM) are used in three different systems.

In water based PV/T system, double absorber plate is used in which top absorber plate is attached to PV panel and second absorber plate is attached to copper pipes having same shape of profile as that of piping arrangement [3]. Photovoltaic (PV) cell's electrical performance is adversely impacted by the significant increase in cell operating temperature during solar radiation absorption. In this work a hybrid solar photovoltaic/thermal (PV/T) system was designed, manufactured and investigated experimentally. To effectively cool the PV cells, a parallel series of inlet / outlet manifold ducts was attached to the back of the PV panel designed for uniform airflow distribution. Experiments were performed with and without active refrigeration. A linear pattern was found between the output and the temperature [4]. This paper provides an overview of the Photovoltaic Thermal Combination System (PV/T Combi), with as one unit a combination of photovoltaic panel with air- and water-based systems. This bi-fluid principle not only generates electrical energy but also simultaneously generates hot air and hot water. This idea was seen from the literature to achieve greater overall energy efficiency, especially in electrical production. That is because heat is multiplied by both air and water media output from the PV module. The combination of these two heat carrier types is intended to cover the shortcomings and weaknesses of individual PV/T water and air heat collectors [5].

PVT systems outperform PV + T systems by 69 percent for all locations, produce between 6.5 percent and 8.4 percent more exergy when compared to pure PV systems and 4 times more exergy than pure solar thermal systems. The results clearly show that PVT systems, which are capable of utilizing all the produced thermal and electrical energy, are superior in exergy efficiency to either PV + T or PV only [6]. The aim of this paper is to determine whether the use of phase-change material (PCM) infused graphite with an external finned heat sink is viable as a method of PV thermal control, through experiment and Matlab modelling. The effect on the thermal output, point-based efficiency, and overall efficiency of a PV panel was studied in four different thermal regulation techniques [7]. PV (photovoltaic) module performance is heavily dependent upon its operating temperature. Some of the energy that the panel consumes is converted to heat that is usually lost and gives little benefit.

To research the performance of a water-cooled hybrid PV system, using EES (Engineering Equation Solver) software, a numerical model (electrical and thermal) is created. The model predicts different thermal and electrical parameters which affect its efficiency. The effect of cooling the module is also experimentally investigated by integrating a heat exchanger (cooling panel) at its rear side [8]. This present study explores the effects of operating temperature on the panel of monocrystalline PV at Perlis, Malaysia. Firstly, a selected PV panel model was simulated using PVsyst software to determine its output value. While, during the sunniest day, PROVA 200 used to calculate and record all the electrical data for experimental outdoors. In addition, the thermal distribution was analyzed using temperatures from PV panels and thermal imaging. Results of simulation suggested that the PV panel's output power decreases as its working temperature rises and the performance follows [9].

METHOD OF OPERATION

A test bench is designed and built for PV-T air-cooled panel. A versatile Photovoltaic panel Power Film R21 shapes the equipment to be tested. A cooling duct is connected to the door, using air to refrigerate the panel at room temperature. The geometry and device components are described using decision-making techniques. A mounting base is built with an inclination equal to the test spot latitude (42.4 °), and with clamping plates for the various probes. Fully shielded from the outside, the cooling duct contains shades in the inlet and outlet to prevent the influence of solar radiation on the sensors. Fig.1 displays a view of the base-mounted test bench.

FIGURE 1: Test bench

The aim of the test bench is to obtain experimental data for designing PV-T Panel performance models. Illustration 2 Shows where the measurement points are located on the PV-T stand. PV panel short-circuit current (A) and open-circuit tension (V) data are recorded for electrical modeling. The temperatures of the cooling air inlet (Tin) and outlet (All) as well as the air flow rate (FR) are reported for thermal modeling. Environmental conditions are also critical for thermal modeling; wind speed is obtained from a nearby weather station, and the incident radiation (SI) on the PV-T panel must be measured on the test bench.

FIGURE 2: test bench schema, showing different measuring points

Arduino-based system

The monitoring and control framework proposed is based on the software platform for Arduino. The selected hardware is calculated according to the device specifications and the architecture proposed.

System requirements

The test bench that was developed records data from the PV-T panel. Reported inertia parameters are quite small, therefore the recording frequency is not critical and it is more than adequate to have one set of sensor measurements per 10s. The selected Arduino model must therefore only have appropriate analog/digital inputs / outputs to acquire solar irradiation, temperature data at various points on the PV-T panel's test bench, airflow, voltage, and current, as well as regulate and track fans rotation speed. Because the test bench is placed on a difficult access terrace, the device sends the data to a remote location via a radio link to be recorded. A server located in the lower floor stores the data calculated.

System architecture and hardware selection

Arduino UNO is the development platform chosen for this program, as it meets the requirements. The Arduino system however needs a few additional shields. One of these is required to record PV-T panel voltage and current data through an RS-232 interface with the Keithley 2000 Multimeter. The other necessary shield is the wireless communication board ZigBee protocol, chosen for this reason due to its moderate wireless coverage, ease of programming and low cost. Illustration 3 Lists the system's final design scheme.

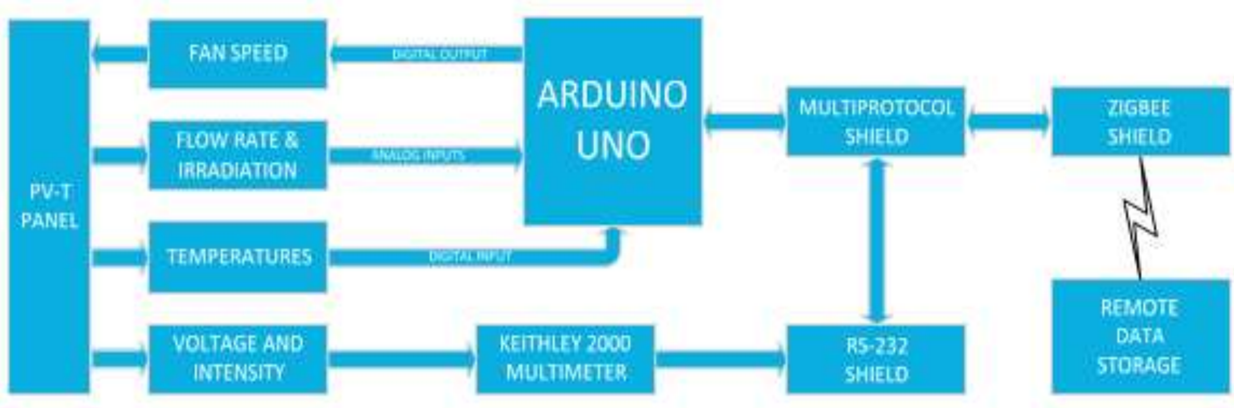

FIGURE 3: System block diagram.

Temperatures are obtained by means of a digital one-wire bus connecting the two temperature sensors which record this parameter. The pyrometer provides an analog output of 4-20 mA, which can be connected to the Arduino through a calibrated resistor. The flow meter provides an analog output of 0-5 VDC, proportional to the measured range.

CONCLUSION

In this work we present the design and construction of an Arduino based PV-T test bench. Testing needs of the test bench for the air-cooled PV-T panel were addressed. An open source, simple, economical and robust framework has been used to provide a proposal solution to these needs. The test bench allows the airflow in the cooling duct to be actuated, making programming tests simpler at various flow rates. In the last six months the system's reliability has been checked without any interruption in data acquisition. Nowadays an innovation is being built in the test bench to automate certain processes, such as data file processing. It also aims to increase the amount of measured temperatures on the PV-T line. This last modification is expected to be simple, because one-wire technology is used by the temperature sensors and only Arduino digital input is used.

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