A LOW-COST MINIATURE PARABOLIC TROUGH CONCENTRATOR AND MONITORING SYSTEM FOR TEACHING AND RESEARCH

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Abstract

Parabolic trough solar concentrators are important components in wide range of medium temperature solar applications. The understanding of the key design parameters and operational conditions on the overall behavior of the system is very important for improving the energy conversion efficiency. To illustrate these dependences and to design monitoring and control systems, a miniature solar parabolic though collector has been designed and built. It considers low cost materials and off the shelf electric components. The system has been used to illustrate the design process, their operation and the design of control and monitoring tools. This type of activities has served to enhance the students' understanding of solar energy conversion processes and the main parameters affecting their efficiency.

Keywords: *Solar concentrators, education and training, automatic control, monitoring system.*

1. Introduction

Solar parabolic trough concentrators are very important component for medium temperature solar technology applications. They have been applied to the generation of high pressure steam for power generation and on a smaller scale for industrial, commercial and residential applications requiring medium range of temperatures. Applications include food processing plant, hydrometallurgical processes, air-conditioning and refrigeration (Kalogirou, 2004; Feranandez-Garcia et.al. 2010; Coccia et. al, 2016).

The conversion efficiency of these concentrators depends on some key design parameters and operational conditions. To illustrate these dependencies and to develop monitoring and controls strategies, it is useful to have as small unit (prototype). Odeh and Abu-Mulaweh (2013) developed a small educational solar tracking parabolic trough to enhance the students' understanding of renewable energy sources and energy conversion processes. The system though small was built to be outside of buildings. Gaitan (2012) presents a smaller system using different materials such as plywood, copper pipes and polished aluminum. The system does not include a data acquisition and control system. In this work, we present a transportable full operational miniature system for teaching and research purposes. A modular design was intentionally selected to investigate the effect of design and manufacturing uncertainties (particularly the effect of rim angle and tracking system) on the performance of parabolic trough collector.

The paper is organized as follows. Section 2 describes the main step considered in the design of the miniature parabolic concentrator. Section 3 describes its operation along with activities that the students can carried out. Conclusions are summarized in section 4.

2. Design

The main design steps considered the following: optical components design, structural design, data acquisition and control system design, construction, programming, and testing. The miniature parabolic trough solar collector, as seen in Fig. 1 a), consists of a parabolic reflector of 1-meter long build using a wood structure and a tin plate covered with a reflective film. The reflector was mounted on a steel structure; the design drawing is depicted in Fig.1 b). A copper pipe was placed close the focal point. The structure supporting this pipe is

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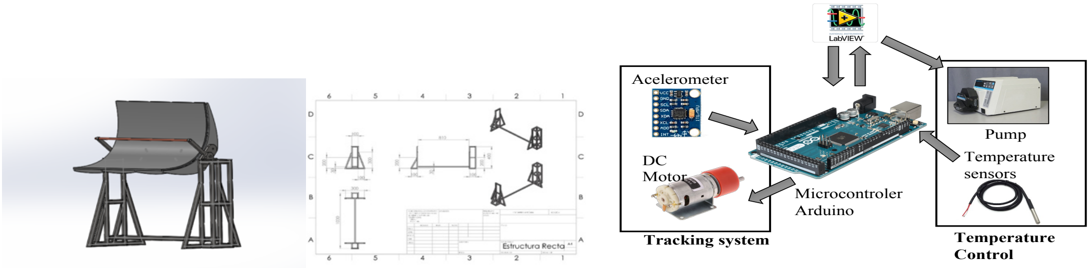
modular and has different positions to illustrate the effect of the design parameters, manufacturing errors and installation errors on the performance of the collector.

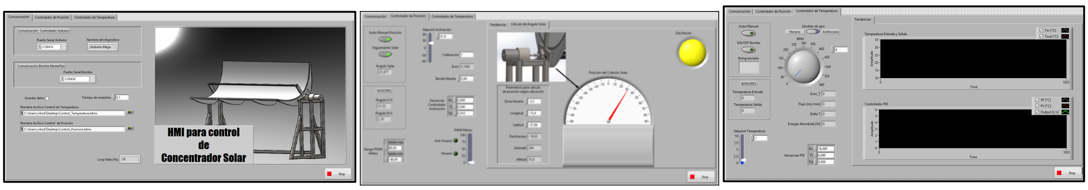
The tracking system comprises a DC motor with gear box and encoder, and a small motor drive. A small power unit of 12 V was used to power the systems. In addition, two temperature sensors were placed at both end of the collector, and laboratory pump was used to control the water flow rate. In addition, a small PV solar cell is used to get an idea about the solar irradiance impinging the system. The useful component of solar radiation (Direct Solar Irradiance) is then retrieved from the global solar irradiance (which is deduced from the PV panel performance) using a mathematical model. All the components were connected to an Arduino microcontroller as depicted in Fig. 1 c). LabVIEW platform was chosen as programing and operation platform, since this was already available and all our student have some knowledge on how to build systems using this platform.



a) Final design **b) Design drawing supporting platform** **c) Electrical components**

Fig. 1: Parabolic trough concentrator

The system is controlled through a Human-Machine-Interface (HMI) having a set of operational screens to ease the operation of the system. Fig. 2 shows different views associated to the HMI. It is possible in this programming environment to develop control strategies for both tracking and temperature control. In addition, simple monitoring strategies for estimating soiling effects can also be developed and tested. The total cost of the system is about US$ 150. This price does not include the pump and LabVIEW license.



a) Initial screen **b) Tracking system** **c) Temperature control**

Fig. 2: Human-Machine-Interface

3. System operation and activities

The operation of the system is carried out through the HMI and all the measurements are stored for further processing. The activities that can be developed are associated with the design and operational aspects. From the design point of view, the student can calculate the theoretical efficiency and then measure the actual efficiency. The most interesting activity is to explain the difference between these two results. In addition, the position of the copper pipe can be displaced and the student can study the effect of manufacturing and installation errors on the performance of the collector. Fig 3. shows the system working indoors and outdoors. The operation of the system is fully automatic and the student can develop practical skills such as controller tuning for both the position tracking and temperature control loops. Fig. 4 shows some tracking results for position and temperature control loops. Tuning temperature control loop is a challenging task due to the time varying time delay associated to the water flowrate. Long time outdoor operation is illustrated in Fig. 5, where the effect of clouds on the differential temperature control loop can be seen. The system is also very useful to develop final year projects (Candia 2018) and test new algorithms for monitoring and control. This set-up has provided the opportunity to senior electrical engineering students to work on a real world parabolic trough and better understand this technology.

Fig. 3: Parabolic concentrator in the lab (left) and in the field (right)

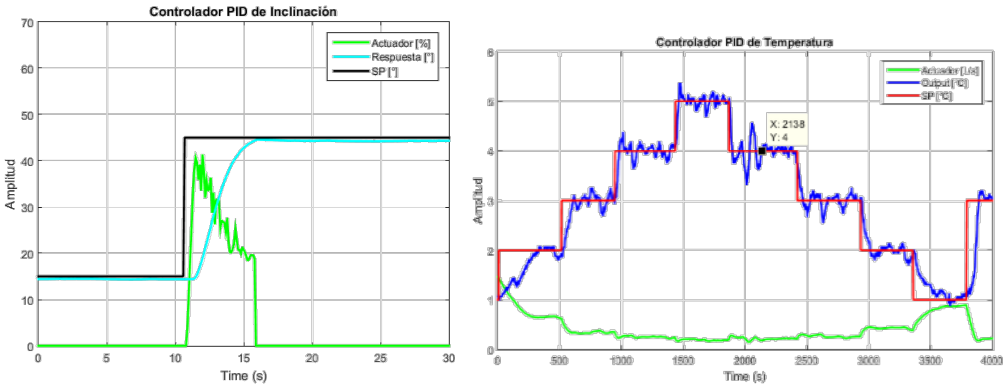


Fig. 4: Tracking and temperature control loops

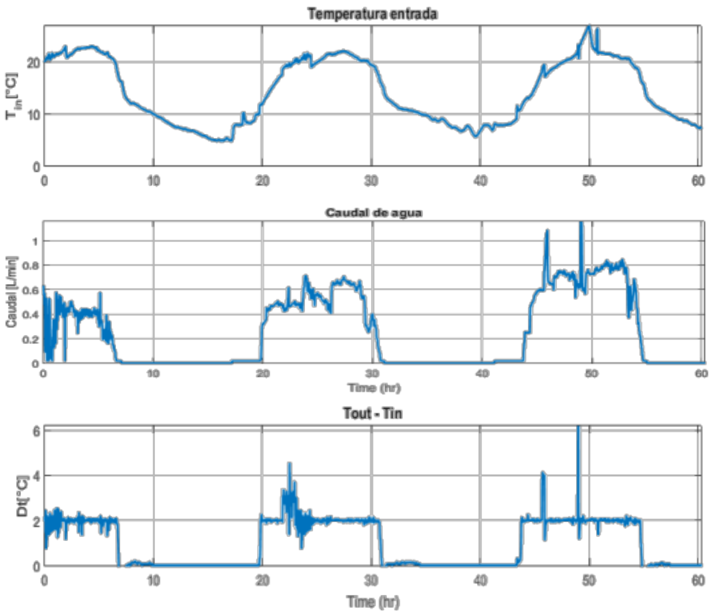


Fig. 5: Outdoor operation. Inlet temperature, water flowrate, temperature difference.

4. Conclusions

This work has presented the design and experiments of a miniature low cost parabolic trough system suitable for teaching and research. The system is portable and can be used outdoor or indoor. It has been designed to be built with simple materials and off the shelf digital components. The system has been used in senior courses on control of thermal systems, as a test bench for final year project on control systems, and as a demonstration unit. Positive feedback from students has been obtained so far. Further work is underway to carry out a formal assessment of the system in an educational setting.

5. Acknowledgments

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