INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
P. Durán Medina et al., Vol.9, No.3, September, 2019

Thermal Energy Generation from a Solar Collector Parabolic Dish Reflector

Pino Durán Medina‡, Juan G. Barbosa Saldaña, Claudia del C. Gutiérrez Torres, Pedro Quinto Diez, Luis A. Moreno Pacheco

Instituto Politécnico Nacional, Escuela Superior de Ingeniería Mecánica y Eléctrica, Unidad Zacatenco, Mexico City, Mexico

(pinoduran@hotmail.com, jbarbosas@ipn.mx, claudia2174@yahoo.com, pqd510@yahoo.com.mx, ls_moreno@hotmail.com)

‡Corresponding Author; First Author, pinoduran@hotmail.com

Received: 10.04.2019 Accepted:27.06.2019

Abstract- A prototype of a small modularity parabolic dish reflector or PDR solar collector with two-axis solar tracking system was designed and built at the National Polytechnic Institute (IPN) in México. The purpose is to generate high temperature thermal energy for application in services of small and medium industry as well as domestic uses. The solar tracking in two-axis was developed based on angular relationships and a control system with proportional-integral action so that even when there is an obstruction of solar radiation either by cloud cover, buildings, trees or any other object that generates shade, the collector remains oriented towards the Sun. For operating and monitoring the prototype, a flow control module and a human machine interface or HMI were developed and implemented, allowing by means of a computer interface, the monitoring of solar radiation, temperature for thermal evaluation. The experimental data obtained indicated that the prototype can generate 30 kg of steam saturated starting from water at an ambient temperature of 298 K.

Keywords- Collector; dish; energy; parabolic; PDR; solar; thermal; tracking

1. Introduction

The energy demand for any country increases as well as the growth in its population, being the traditional combustibles the main source for supplying the population energy requirements. However, the excessive use of fossil combustibles has become prohibitive due to the environmental problems as the global warming, also is the fact that the reserves of petroleum are wasting away and there is incertitude about the amount in the reserves, and the high dependence of the petroleum jeopardize the future in terms of energy use [1, 2]. Contrary to the conventional energy sources, the sustainable energy sources present a real alternative to produce the energy requirement for the society, in addition some of them are everlasting and do not produce negative effects to the environment. At the same time, these alternatives have an important role in the near future to provide the energy to the global world because the development of a country will be in close relation to the technological development of sustainable strategies for producing the energy its society requires [3-5]. In this sense, solar energy is the highest energy source since it is a renewable resource that is clean, economical, and has less pollution compared to other resources and energy [6, 7]. It is estimated that in 84 minutes arrives to the earth near to 900 EJ of energy from the sun, that is equivalent to the total annual world demand of energy [8], although we are utilizing the fraction of it, it is capable of fulfilling the world's energy demand to a large extent [9]. In specific, the average daily solar radiation impinging Mexico is 5.9 kWh/m^2-day [10], this value gives a clear idea of the solar resource and its potential availability for being use as energy source for industrial, service and domestic applications.

Several technologies have been developed in order to use the solar energy for producing energy. The efficiency of these technologies depends on the way of collecting the solar resource, being the most widely used the flat plate collectors, which reach temperatures of the order of 60 degrees then their applications are limited to low thermal conditions, in addition an enormous collecting areas are needed for providing important amounts of energy [11]. Alternate options for supply thermal energy of high quality are the concentrating collectors such as the solar dish or parabolic

Nomenclature		**Acronyms**	
Dispersion angle	δ	Parabolic Dish Reflector	**PDR**
Maximum concentration ratio	**Cmax**	Programmable Logic Controller	**PLC**
Rim angle	φ_r	Proportional-Integral	**PI**
Incident angle	θ	Human Machine Interface	**HMI**
Zenith angle	θz		
Inclination angle of the collecting surface	β		
Solar azimuth angle	γs		
Azimuth angle of the collecting surface	γ		
Altitude angle	α		
Normal to horizontal plane	n_h		

dish reflector (PDR). In particular, this technology is the only way to get high temperatures from the sun radiation on earth [12] and the most efficient way for producing electric energy and in some cases an efficiency of 25% can be reached [13]. The PDR devices are tools for capturing the solar energy, if the direction of light beam to be along the symmetry axes of the parabolic reflector surface, the instrument concentrates it in a small area with high irradiance. The solar dish can produce electric energy or other kinds of energy too. It is important that the parabolic dish is along the sun direction. To get this, a computer programing and apparatus based on astronomical data and calculations are usually employed [14].

The whole system for solar alignment is defined as tracking system, different authors give the classification according to the movement capability, three main types of sun tracker can be found: fixed surfaces [15], single-axis trackers [16] and two-axis trackers [17]. The concentrated solar technologies require the use of two-axis tracking system, with the exception of trough-style systems, which require only single-axis tracking. Unfortunately, in comparison with the single-axis tracker, two-axis trackers are often complex and, therefore, also unreliable and expensive, trackers alone can constitute up to 40% of the capital cost for collectors systems [18]. As the sun's position changes throughout the day, the solar tracker is a more efficient method of increasing the energy production. So the solar tracker is being studied by more and more researchers [19]. Even more, Abdallah and Nijmeh [17], mentioned that a two axis tracking systems increases over 75% in the collected energy when compared with an identical fixed system. In their work, they design a two axis tracking system controlled by a PLC system and an electromechanical set up.

According to El Jaouhari and co-workers [20], recently the trackers systems are based on electronic circuits and mechanisms driven by control motors and some of them are based on photo sensors which are extremely inefficient in cloudy days. In their work, they proposed a computer vision technique in addition to a programmed algorithm to identify the brightest region and then align the motors to the right angles to positioning the concentrator towards the sun. Even though this technique is extremely accurate, the cost could be prohibitive due to the implementations of sophisticated image acquisition system. An alternative is the combination of electronic micro controller unit and GPS information to find the sun position which is presented in other work [21].

In the other hand Mawire and Taole [22] indicated that several efforts have conducted for studying the performance of small scale parabolic dish concentrators for domestic applications.

In particular, in Mexico the PDR technology is new and until now their applications have been focusing to high scale applications, mainly for steam production for supply thermoelectric power plants. Here, the principal feature for its high efficiency is related to the fact that the collector is directly positioned to the sun, by means of a two-axis solar tracking system, however, these movements consume important quantities of energy in addition to their elevate cost for construction and maintenance [23].

The design and construction of a solar collector PDR prototype with two-axis solar tracking system is the main point in this work. The particularity of the project is that the PDR has a small modularity without use costly and complex sensors, devices and control systems in order to produce high thermal energy for applications in the small and medium industries, service and even domestic applications. The solar tracking system was designed to work following the sun´s path by just introducing the geographical position, with the particularity of a closed loop for each axis by the implementation of precision potentiometer in order to measure the angular displacement with the performance of a Proportional-Integral action control. The PDR´s design and its operation are described in sections below.

2. PDR solar prototype

When designing a solar collector, the main objective is obtained the maximum of the solar radiation and transforms it into a useful form of energy. In the case of a PDR the sun tracking is the most important feature that directly impacts the thermal efficiency of the system, in this case it has been reported that the sun tracking increases in 30% the efficiency [24]. Another important geometric feature to be consider is the concentration ratio that can be defined as the maximum of radiation obtained, based on interception of all of the specularly reflected radiation contained within the cone of angular width 0.534+δ [25]. According with Duffie and Beckman [26], mathematically this value can be computed from equation (1).

$$C_{max} = \frac{sen^2(\varphi_r)*cos^2\left(\varphi_r+0.267+\frac{\delta}{2}\right)}{4sen^2\left(0.267+\frac{\delta}{2}\right)} - 1 \quad (1)$$

The inclusion of the factor δ, named dispersion angle, allows the consideration of angular errors associated to an inadequate solar sun's tracking, rugosity on the surface's reflexion, and an inappropriate curvature in the dish reflector. In other words, depending on this parameters it can be know the increases in the amplitude of the reflected radiation in the concentrator. These errors have been experimentally obtained making use of statistics tools [27].

From equation (1) it can be observed that the concentration ratio depends on the rim angle, and a maximum in the concentration ratio is obtained when it is fixed at 45 degrees, resulting in a Cmax real = 280. Due to these values result in a maximum of concentration, then these parameters was considered for sizing the parabolic dish.

Once the rim angle for a maximum concentration ratio is fixed, it is needed to compute the optimums mirror radius and focal length for producing in the focal point an image the large enough for installing a device that captures the reflected energy and then transforms it into thermal energy. The small modularity proposal must to be satisfied in accordance to the objectives of the project.

According to the before mentioned criteria, dish's diameters smaller than 1m produce an extremely small focal images to allocate a functional heat exchanger in the focal point. In the other side, diameters larger than 1.75 m are too large for being considering as a small modularity PDR. The alternative is proposing a dish´s diameter in the range of 1 to 1.5 m [28]. Hence, the dish diameter choose was 1.5 m, because this dimension allowed the largest size in the image and then a better use of the solar resource will be obtained. Table 1 summarizes the geometrical dimensions and technical specifications of the small modularity PDR.

The absorber is located at the focal point of the parabolic dish and all the radiative energy will be concentrated in this point in order to convert the solar radiation into thermal energy. Once the radiative energy is focused in the absorber a working fluid is forced to pass through the absorber. As result of convective heat transfer the fluid flowing through the absorber will increases its temperature. For this project, the absorber is a 0.15 m in diameter and 0.05 m high cylindrical cavity built in stainless steel. The dimensions where computed according to the optimal image size.

Table 1. Technical specifications of the concentrator dish

Characteristic	Specification
Collecting area	12.55 m2
Rim angle	45°
Diameter	1.5 m
Focal length	0.9 m
Mirror radius	1.06 m
Focal image	0.15 m
Dish body material	Fiberglass
Reflecting film	Mylar
Mylar reflectivity	0.85
Total weight	20 kg

2.1. Solar tracking.

In order to get the most of direct solar radiation incident in the PDR some devices have been equipped with a solar tracking system, in addition this mechanism allows to diminish the solar incident angle impacting positively in the energy captured by the reflector and increase their efficiency [17]. An ideal tracker would allow the PDR to accurately point towards the sun, compensating for both changes in the altitude angle of the sun to track the sun throughout the day, latitudinal offset of the sun during the seasonal change and changes in azimuth angle [29].

There are several tracking system, the most appropriated for a PDR is the two axis tracking. Even though it is the most expensive, it is the most efficient, because the PDR all the time is directly aligned to the sun. According to Duffie and Beckman [26] the solar position in the sky depends on the day, the latitude and the longitude and can be computed by means of the following relations:

$$Cos\,\theta = 1 \quad (2)$$

$$\beta = \theta_z \quad (3)$$

$$\gamma = \gamma_s \quad (4)$$

The equation (2) implies that the axis normal to the collector's surface is always aligned to the sun; hence the incident angle θ must be equal to zero. In addition, in equation (3) the inclination angle of the collecting surface β has to be equal to the zenith angle θz. The zenith angle is measured between the normal to the horizontal plane and the sun position, resulting in the sun's altitude α. The relation in equation (4) establishes equality between the sun´s azimuth angle γs and the collector´s azimuth angle γ. It can be said that for a correct tracking of the sun, it is necessary to obtain the solar azimuth angle γs and the altitude angle α, according to Fig. 1. The complete mathematical development of the before mentioned angles can be detailed found in Duffie and Beckman [26].

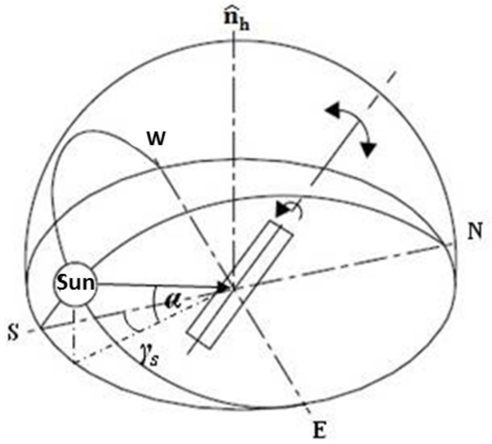

Figure 1. Two-axis solar tracking configuration [11].

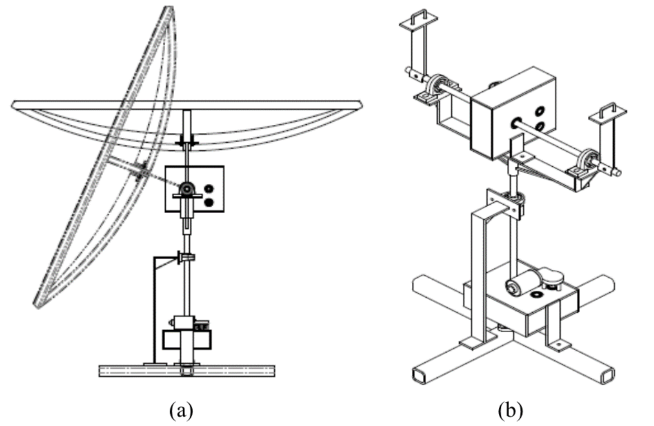

Figure 2. General design of the mechanical structure for the solar collector tracking system. (a) Lateral view. (b) Isometric view.

2.2. Mechanical support and movement system.

The tracking system designed for the small modularity PDR is divided in two parts. The first one consists on a pair of gear boxes that moves two axes, one in azimuth direction and the other in elevation axis; together they conform the two axis tracking system. The second one is associated to the mechanical structure to support the entire system including the dish reflector.

The mechanical composition and design of the boxes gear is an important aspect for the PDR, because is by their activating that each axis is precisely moved, and the sun´s path can be reproduced by the system. In summary, a group of four gears are working together such that for a half of a revolution of the motor, each axis is displaced one degree. A complete description of these mechanisms can be found in previous work by the author [28]. Fig. 2 shows a schematic diagram of the structure and the position of each box gear that works in conjunction to make possible the two axis tracking system. The mechanical structure is made of stainless steel to resists the corrosive effects of the environment and is the strong and rigid enough to give flexibility and support to the entire PDR system.

3. Automatic solar tracking system

The successful of the concentration collectors is associated with the aligned of the solar device respect to the sun. Some authors specify that the thermal efficiency can be increased if the dish is all the time oriented towards the sun [30].

Generally there are well-known kinds of control systems for solar energy tools and so much researches have been done about them. We can classify them according to their performance in five parts: (a) Passive; (b) Microprocessor; (c) Electro-optic; (d) Microprocessor and electro-optically control systems [9] and (e) Modern computerized control systems [17, 21].

The passive systems track the sun without any electronic controls or motors [31, 32], one type of this performance utilizes the concept of materials thermal expansion [21]. The sun tracking systems supported by microprocessor controller (without the optical sensors) are based on mathematical relations for finding the sun direction [14]. The electro-optic performance utilizes photo sensors used to discriminate the sun's position and send electrical signals proportional to the error to the controller, which actuates motors to track the sun. Many authors have adopted this method as a basis in construction and design of solar tracking systems [17]. The newest types of the controllers are those that use both the microprocessor and electro-optically control systems where they are very practical for exact measurements, such as a control device based on computer image processing of a bar shadow [14]. Finally the modern computerized control systems are those based in a programmable logic controller (PLC) control system or in a fuzzy control system [24, 33].

For this project the solar tracking is based on the angular relations before mentioned in previous section, such that the collector is always in direct line to the sun, even if there are clouds, buildings, trees or any other object that can be a potential obstruction of the solar radiation. The PDR is receiving all the radiation and operates at a maximum temperature keeping the working substance at a high temperature most of the time. A detailed description of the control strategy for the small modularity PDR will be described next.

3.1. Control system

The controller is the element where all the electronics is allocated in order to provide an adequate answer for the mechanical devices that work for producing the movement for tracking the sun's path. Is in this part where the algorithm is programmed in order to obtain the correct angles and produce the electric pulses for manipulating the motors for each axis. Physically, the controller is a microprocessor, its own software and a minimum power system for its operation.

In a first stage the control strategy implemented for the PDR is the kind of closed-loop with an integral-proportional or simply PI control action. Here, it is pretended to obtain a better control in the motors activation thanks to a feedback electric signal that ensures the correct position for each axis. Two control loops are programmed, both of them with the same control strategy and one is destined for the azimuthal axis (0°-180°) and the other one is for the elevation axis (0°-90°). It is important to mention that for a displacement equivalent to one degree, in the motor it is necessary half of a revolution. Figure 3 is used to show the flow chart for the control strategy.

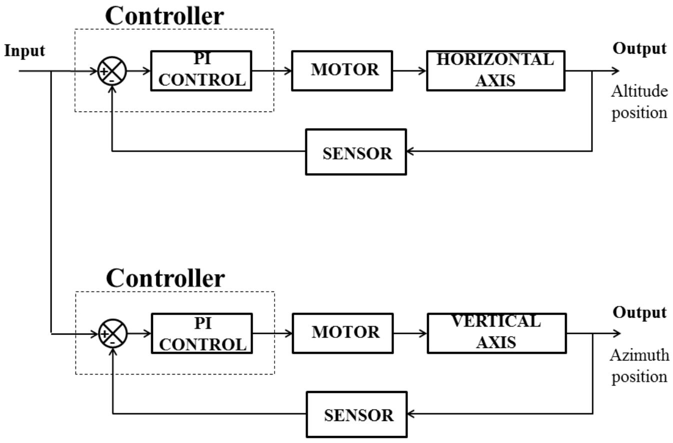

Figure 3. Control system block diagram.

The positioning of the PDR is the medullar part of the microprocessor and starts with the input of data as date, time, latitude, longitude, and standard longitude, where the PDR system will be installed. Once this information is given, the microprocessor computes the operations and sends the activation signals to the control board to each motor. These control boards are dual, with the purpose of inverting the polarity, for allowing both directions of motor rotation. This board is the responsible of turning on and turning off the motors for azimuth and elevation.

The control system warrants the movement making a gradual displacement for the angular movement in the motors, ensuring that the azimuth and elevation positions of the sun are correctly reproduced and the PDR is directly aligned to the sun. Once the movement has been produced, the angular displacement is measured by means of a 10 kΩ precision potentiometer coupled to each axis, this signal is feedback and compared with the theoretical angular position, in such manner that an error signal is obtained and it will be corrected by the controller. Each potentiometer works at 5 V DC, such that the output voltage is a reference for the displacement angle for each axis. In fact that the sun moves at a rate of 15° per hour [34], the tracking system is not continuously in movement, however a movement in the system depends on the error magnitude between the focal point position and the sun.

3.2. Fluid flow control

To convert the solar radiation impinging in the PDR in thermal energy, a fluid flow is forced to pass through the absorber as can be appreciated in Fig. 4.

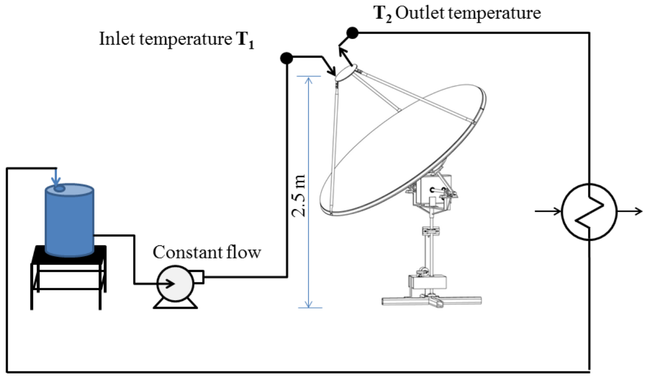

Figure 4. Process diagram for forced convection into the collector.

To obtain the highest temperature at the exit of the absorber, the working fluid must to remain the maximum time inside the absorber; hence it is necessary to work with small flows, in the order of 1 to 3 lpm. In this sense, a computer interface for controlling and measure the flow was built, as can be appreciate in Fig. 5. The flow control module uses a 24 V pump, an electronic flow sensor, and a local flow meter. The control flow system is automatized by means of an independent electronic controller that is synchronized with the principal controller.

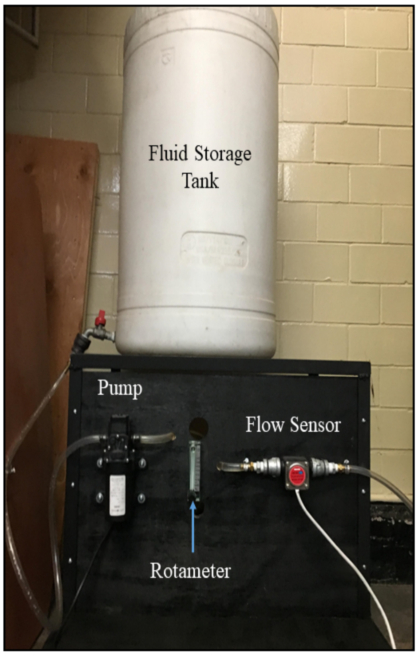

Figure 5. Flow control module prototype.

Table 2. Summary of accuracy, uncertainty and resolution for experimental measurements.

Instrumentation	Model	Range	Resolution	Units	Accuracy	Uncertainty
Pyranometer	MacSolar	0-1500	1	W/m2	±1	< 3% ±1
Rotameter	MMA-42	0.3-3.5	0.25	lpm	±4 %	--
Electronic Flow sensor	OF-201	1-10	0.005	lpm	±2 %	--
Thermocouple	J	0-900	0.001	°C	±0.001	--

For operating the entire PDR system; including the two axis tracking and the fluid flow control, it was developed a HMI interface as can be appreciated in Fig. 6. With this application the entire operation is extremely simple, allowing the register of the process variables as flow, temperatures at the inlet and output of the dish, and the tracking position. A summary of the accuracy, uncertainty and resolution of the main measurement devices used for the experimentation is provided in the Table 2.

4. Results and discussion

For testing the tracking system it was necessary to characterized the movement's sensor coupled to each axis and determine the maximum and minimum real resistance as shown in Table 3, then the averaged value were fixed as the reference initial value.

Table 3. Values given by the potentiometer.

Value	Resistance	Voltage
Minimum	1.90 KΩ	0.09 V
Middle	2.74 KΩ	2.69 V
Maximum	9.42 KΩ	4.93 V

A relation between the voltage values and the angular displacement obtained after several measurements for the operating range for each axis is obtained in order to calibrate the sensors. Table 4 shows the correspondence for each measurement. These values will be given as data to the HMI for the correct alignment of the parabolic dish.

The PI controller adjusted was made by the Ziegler-Nichols [35] method. This implementation produced the gain for each axis according to the values in Table 5.

After the controller is adjusted and the relation to the angular displacement and voltage are fixed, the next step is to find the reference signal (set point) based on the relations for the azimuth and altitude angles for the geographical location where the testing is made. In the present case this values were fixed for latitude 19.5°, standard longitude -90°, local longitude -99°. The computed results are compared to the position of the tracking system as can be seen in Table 6.

The results showed that the control is excellent to align the tracking system in the sun position and therefore the azimuth and altitude angles are completely well reproduced. In the worst case a difference of two degrees is presented for altitude angle, as reported in table 6. The maximum error found in the alignment falls in the acceptable order or error reported in the specialized literature [21]. In order to verify the performance of the tracking the estimation of the focused radiation and the temperature on the absorber´s surface for different testing proofs were developed.

Table 4. Relationship between angular displacement and voltage output given by the potentiometer in each axis.

Azimuth		Altitude	
Grades	**Voltage V**	**Grades**	**Voltage V**
179	4.09	90	2.61
135	3.72	85	2.48
90	3.29	80	2.37
45	2.87	75	2.29
0	2.48	70	2.15
-45	2.07	65	2.04
-90	1.66	60	1.98
-135	1.24	55	1.87

Table 5. Gains for PI controller.

Axis	Kp	Ki
Altitude	2.7	3.8
Azimuth	9.93	7.21

It is important to mention that the proposed prototype as well as the control strategy depend only on the coordinates where the system will be installed, and once it has been determined that the operation is appropriate, it can be said that the use of the system is global for any point around the world, and the results of the alignment will be adequate.

The proposed tracking strategy properly operates even for cloudy or not favorably weather conditions. It can be said that the control and the HMI make easily the manipulation and operation of the dish orientation. In this sense, the easiness of the interface also allows the data acquisition for evaluation of the system. For proving the thermal capability of this solar prototype the thermal evaluation was conducted and the results are described next.

The focused solar irradiation on the absorber was computed considering the measured solar radiation incident in a horizontal plane. The instrument was a pyrometer calibrated under an air mass of 1.5, a GT = 1000 W/m2 at 25° C. Based on these measurements the Erbs's correlation [36] was used for computing the direct solar radiation normal to the dish's aperture. This flux was used for evaluating the useful energy in the absorber. The temperature in the absorber was monitored by means a J thermocouple class 2, with an operating range from -40° C to 750° C.

Figure 7 shows the experimental results obtained for a testing day. In the figure the total solar irradiance and the temperature at the absorber surface are plotted in the vertical axes while the horizontal axis is for the local time. It can be shown that there is a closed relationship between the solar irradiance and the temperature in the absorber. Specifically, in this test the alignment of the parabolic dish has a response time of approximately 4 minutes. This means, that approximately after a period of 4 minutes, the system was out of focus and the control system needs to computes and activate the mechanism in order to find the exact position of the sun in the sky and then align the parabolic dish to the right sun angles.

The control system operates in a period of updating the alignment each 4 minutes, but also the control allows the tracking in real time. In the second case, the energy required can be excessive, but in the first operation mode there is a small disarrangement in the alignment, however this can be neglected because it does not have a real impact when computing the efficiency.

For computing the thermal gain in the system it was considered as a working fluid a synthetic oil with an ebullition point fixed at 300° C. The total mass of fluid was 30 liters and different flows where tested. The mass flow was registered by an electronic sensor (0 lpm – 3 lpm) as well as by a rotameter (0 lpm – 3.5 lpm) while the temperature was measured with a thermocouple J class II. All the data were obtained by means of the HMI module before described.

Figure 8 shows the temperature obtained at the exit of the solar system for different operating flows. The flows were 1.5 lpm, 2 lpm and 2.5 lpm. The maximum temperature was superior to the 90° C for an exposed period of 3 hours.

If a high efficient heat exchanger is adapted at the output of the PDR, according to the results, the energy gained in the system could be high enough for obtaining 30 kg of saturated water steam, coming from a temperature of 25° C. In a similar way, a total mass of 100 kg can be heated to a delta of temperature of 25° C.

In terms of the energy production, it can be said that the prototype is good enough for supplying an appropriate amount of energy that can be destined for industrial, hospital services and domestic applications. Its small modularity, as well as the control strategy makes the prototype an excellent alternative and sustainable option for a low cost provided of high quality thermal energy.

Table 6. Comparison of ideal angles with angles generated by the control system.

Day hour	**Ideal angles**		**Generated angles**	
hrs	**Azimuth**	**Altitude**	**Azimuth**	**Altitude**
11:00	**-69**	**47**	**-70**	**45**
11:30	**-64**	**53**	**-64**	**54**
12:00	**-56**	**59**	**-55**	**60**
12:30	**-45**	**65**	**-45**	**65**
13:00	**-29**	**69**	**-30**	**69**
13:30	**-7**	**72**	**-7**	**70**
14:00	**16**	**71**	**16**	**71**
14:30	**38**	**68**	**38**	**68**

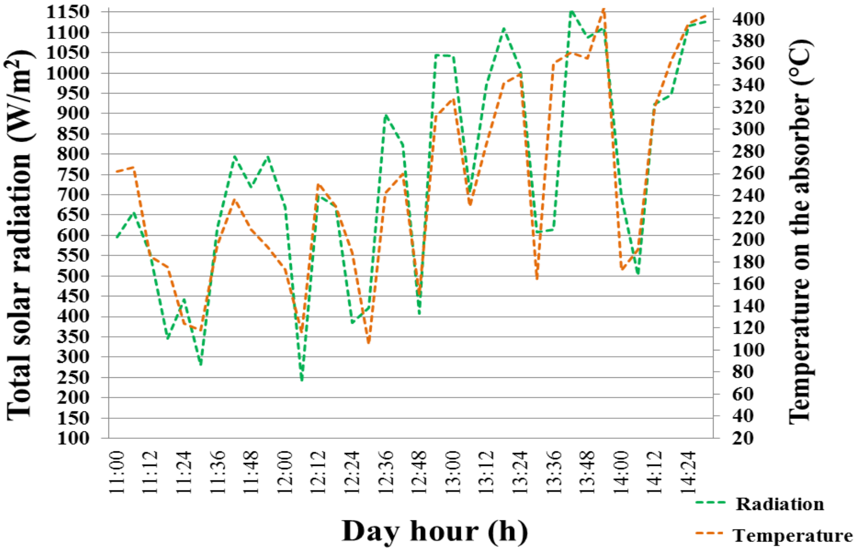

Figure 7. Temperature on the absorber element with respect to solar radiation.

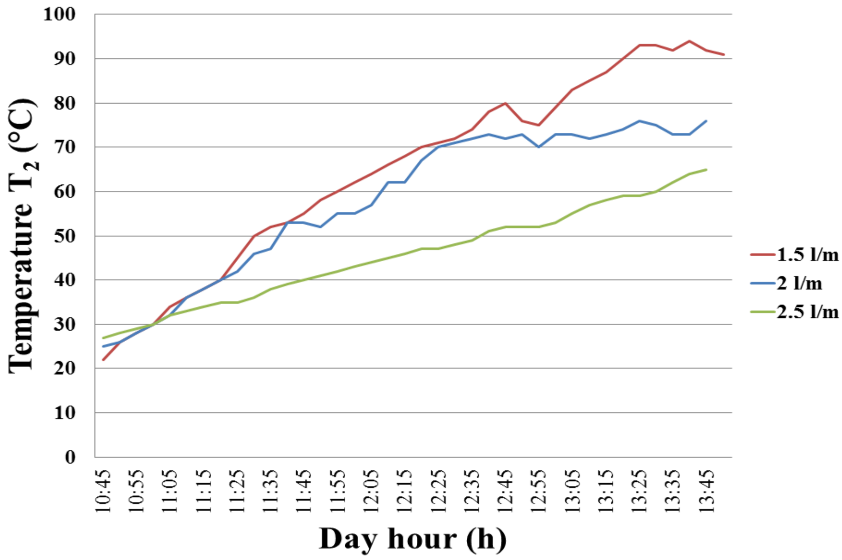

Figure 8. Temperature increase in T_2 at the outlet of the solar collector.

5. Conclusion

A small modularity solar collector PDR prototype with a two-axis solar tracking system based in a microprocessor control system performance have been designed and built in the IPN in Mexico. This prototype works for any geographical position.

The correct alignment of the device needs the geographical coordinates as input data, and by means of the closed loop and the precision potentiometer each axis is aligned for the required position; after that, the control implemented is a simple PI controller giving a progressive movement to the system, reducing the instabilities and vibrations in the axis when the motors are in movement.

In addition, this control system provides an excellent alignment to the sun path, making the control system appropriate for operate a PDR and making it high efficient for heating process. According to the results, a maximum error of 2 degrees was obtained in the worst case, when the system was tested.

The implementation of the HMI makes extremely easy the operation of the PDR system, and even gives an opportunity for an easy monitoring of the operating variables in the solar heating process.

Finally, the reached temperatures showed that the operation of a small modularity PDR is possible without the implementation of complex and expensive sensors, control systems and solar tracking devices, and can be useful for attend the demands of thermal energy for domestics and small industry applications.

Acknowledgments

The Institutional Scientific Research and Technological Development Program gave the economical funds for the development of this project.

The COTEBAL program of the Instituto Politécnico Nacional in Mexico authorized the first author for developing and colaborating in this project.

The CONACyT granted the scholarship to the student.

References

[1] P. N. Patil et al., "Automatic Dual-axis Solar Tracking System for Parabolic dish", Proceeding IEEE - 2nd Int. Conf. Adv. Electr. Electron. Information, Commun. Bio-Informatics, IEEE - AEEICB 2016, pp. 699–703, 2016.

[2] B. Abdelhakim, C. Ilhami, and K. Korhan, "A comprehensive study of different photovoltaic peak power tracking methods," *2017 6th Int. Conf. Renew. Energy Res. Appl. ICRERA 2017*, vol. 2017-January, pp. 1073–1079, 2017.

[3] A. El Fadar, "Automation of a solar adsorption refrigeration system", Proc. 2013 Int. Renew. Sustain. Energy Conf. IRSEC 2013, pp. 118–122, 2013.

[4] K. D. Mercado, J. Jiménez, and C. G. M. Quintero, "Hybrid renewable energy system based on intelligent optimization techniques," *2016 IEEE Int. Conf. Renew. Energy Res. Appl. ICRERA 2016*, vol. 5, pp. 661–666, 2016.

[5] G. M. Vargas-Gil, J. C. Colque, A. J. Sguarezi, and R. M. Monaro, "Sliding Mode plus PI Control applied in PV Systems Control," *2017 6th Int. Conf. Renew. Energy Res. Appl. ICRERA 2017*, vol. 2017-January, pp. 562–567, 2017.

[6] B. Ahmmad, Y. Kitamura, Y. Kusumoto, H. Yang, and M. Abdulla-Al-Mamun, "A New Type of Solid State Solar Cell Based on Fe2O3, SiC and Crystal Growth Inhibitors," J. Sci. Res., vol. 2, no. 1, pp. 1–8, 2009.

[7] B. Ahmmad, Y. Kusumoto, M. Abdulla-Al-Mamun, A. Mihata, and H. Yang, "Effect of Single Walled Carbon Nanotube as Counter Electrode on Laser-deposited Fe2O3 and TiO2 Films Solar Cells," J. Sci. Res., vol. 1, no. 3, pp. 430–437, 2009.

[8] A. Sandoval. "El Ocaso de la era del carbón," [Online]. Available at: http://www.anes.org/cms/contenido/docs/revista/RER_32.pdf

[9] H. Soonmin, A. Lomi, E. C. Okoroigwe, and L. R. Urrego, "Investigation of Solar Energy : The Case Study in," vol. 9, no. 1, 2019.

[10] Instituto de Investigaciones Eléctricas, "Explorador de Recursos Renovables," [Online]. Available at: http://sag01.iie.org.mx/eolicosolar/Default.aspx#>

[11] S. Kalogirou, Solar Energy Collectors, 1st ed., Academic Press, 2009, pp. 121-150.

[12] M. H. Ahmed, M. Rady, A. M. A. Amin, F. M. Montagnino, and F. Paredes, "Comparison of thermal and optical performance of Linear Fresnel and Parabolic Trough Concentrator," *2015 Int. Conf. Renew. Energy Res. Appl. ICRERA 2015*, vol. 5, pp. 626–629, 2015.

[13] M. A. Sodestrand, "Mini-Dish Based Hybrid Concentrated Solar Power (CSP) System for Home Use", IEEE 56th International Midwest Symp. Circuits Syst., pp. 689-692, 2013.

[14] H. Arbab, B. Jazi, and M. Rezagholizadeh, "A computer tracking system of solar dish with two-axis degree freedoms based on picture processing of bar shadow," Renew. Energy, vol. 34, no. 4, pp. 1114–1118, 2009.

[15] M. M. H. Prodhan, M. K. Hamid, D. Hussain, and M. F. Huq, "Design, Construction and Performance Evaluation of an Automatic Solar Tracker," J. Sci. Res., vol. 8, no. 1, pp. 1–12, 2016.

[16] V. Poulek and M. Libra, "Very simple solar tracker for space and terrestrial applications," Sol. Energy Mater. Sol. Cells, vol. 60, no. 2, pp. 99–103, 2000.

[17] S. Abdallah and S. Nijmeh, "Two axes sun tracking system with PLC control," Energy Convers. Manag., vol. 45, no. 11–12, pp. 1931–1939, 2004.

[18] L. Barker, M. Neber, and H. Lee, "Design of a low-profile two-axis solar tracker," Sol. Energy, vol. 97, pp. 569–576, 2013.

[19] Y. Yao, Y. Hu, S. Gao, G. Yang, and J. Du, "A multipurpose dual-axis solar tracker with two tracking strategies," Renew. Energy, vol. 72, pp. 88–98, 2014.

[20] Z. El Jaouhari, Y. Zaz, S. Moughyt, O. El Kadmiri, Z. El Kadmiru, "Dual-axis solar tracker design based on a digital hemispherical imager", J. of Solar Energy Engineering, vol. 141, pp. 011001-1-011001-8, 2019.

[21] M. H. M. Sidek, N. Azis, W. Z. W. Hasan, M. Z. A. Ab Kadir, S. Shafie, and M. A. M. Radzi, "Automated positioning dual-axis solar tracking system with precision elevation and azimuth angle control," Energy, vol. 124, pp. 160–170, 2017.

[22] A. Mawire and S.H. Taole, "Experimental energy and exergy performance of a solar receiver for domestic parabolic dish concentrator for teaching purposes", Energy and Sustainable Development, vol. 19, pp. 162-169, 2014.

[23] E. Venegas, "Sistema para generación y almacenamiento de calor de proceso mediante un concentrador solar de foco puntual (cospaa-90)", Centro de Investigación Eléctrica, UNAM, Morelos, Mexico, 2008.

[24] Y. Goswami, Solar Thermal Power, 3rd ed., CRC Press, 2015, pp. 442-450.

[25] P. Durán, "Concentrador Solar PDR con Seguimiento Solar", ECORFAN Revista de Aplicaciones de la Ingeniería, vol 3(9), pp. 98-108. 2016.

[26] J. A. Duffie and W. A. Beckman, Solar engineering of thermal processes, 3rd ed., John Wiley & Sons, Inc., 2009, pp. 336-370.

[27] W. Stine, Solar Energy Fundamentals and Design with Computer Applications, 1st ed., John Wiley & Sons, Inc. 1985.

[28] P. Durán, "Diseño y construcción de un prototipo de concentrador solar parabólico de disco reflector para generación de energía térmica", Sección de Estudios de Posgrado e Investigación, ESIME Zacatenco, Instituto Politécnico Nacional, Mexico City, Mexico, 2012.

[29] C. Y. Lee, P. C. Chou, C. M. Chiang, and C. F. Lin, "Sun tracking systems: A review," Sensors, vol. 9, no. 5, pp. 3875–3890, 2009.

[30] A. A. Sagade and N. N. Shinde, "Experimental analysis of effect of variation of convection heat losses on performance of parabolic dish collector with nickel chrome coated receiver", 2011 World Congr. Sustain. Technol., pp. 107–111, 2011.

[31] A. Scientific and T. H. E. S. Reports, "Fundamental Sciences and Anniversary Scientific Conference 2006," vol. 13, no. 7, 2006.

[32] S. Ghabusnejad, A. Majdi, and S. A. Davari, "Using P & O Based Sensorless Method In Single- Axis Solar Tracker," vol. 9, no. 1, 2019.

[33] K. Basaran and N. S. Cetin, "Designing of a fuzzy controller for grid connected photovoltaic system's converter and comparing with PI controller," *2016 IEEE Int. Conf. Renew. Energy Res. Appl. ICRERA 2016*, vol. 5, pp. 102–106, 2017.

[34] S. Wieder, Radiative emission from the Sun, An introduction to solar energy for Scientists and Engineers, 1st ed., John Wiley & Sons, Inc. 1982.

[35] M. A. Solorzano, "Control y monitoreo de un prototipo de concentrador solar de disco parabólico reflector para la generación de energía térmica", Sección de Estudios de Posgrado e Investigación, ESIME Zacatenco, Instituto Politécnico Nacional, Mexico City, México, 2017.

[36] D. Erbs, "Estimation of the diffuse radiation fraction for hourly, daily, and montly-average global radiation", Solar Energy, vol. 28, no. 4, pp. 278-293, 1982.