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Design, Construction, and Control Tracking of Solar Thermal Concentrator by Using PLC in Erbil

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ABSTRACT

This paper demonstrates the construction designing analysis and control strategies for fully tracking concentrated solar thermal by using programmable logic control in the city of Erbil-Iraq. This work used the parabolic dish as a concentrated solar thermal. At the focal point, the collected form of energy is used for heating a (water) in the receiver, analyzing this prototype in real-time with two different shapes of the receiver and comparing the results. For tracking the parabolic dish, four light-dependent resistors are used to detect the sun's position in the sky so that the tracking system follows it to make the beam radiation perpendicular to the collector surface all of the time during the day for maximum solar power energy. This work discusses the essential stages of a two-axis prototype; implementation, solar-location strategy, the analysis in terms of theory, structural design, and material. For two-axis-prototype is implemented with the help of programmable logic control -Siemens (S7-1200) as a control unit. This study results show that a parabolic dish tracker with a cylindrical conical receiver obtains 15.25% Improved efficiency in comparison to the cylindrical receiver. According to the testing results of the prototype design, both shapes of the receiver are convenient for steam production.

Keywords: Solar-thermal-concentrator, Parabolic-dish, Tracking-system, Receiver, PLC.

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تصميم, بناء, والتحكم في تتبع الطاقة الشمسية الحرارية المركزة باستخدام PLC في اربيل

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الخلاصة

توضح هذه الورقة تحليل وتصميم البناء واستراتيجيات التحكم للتتبع الكامل للحرارة الشمسية المركزة باستخدام Programmable logic control في مدينة أربيل – العراق. وقد استخدم في هذا العمل صحن القطع المكافئ الشمسي باعتباره حراريًا شمسيًا مركّزًا. في النقطة المحورية، حيث يتم استخدام هذه الطاقة المجمعة لتسخين (الماء) في جهاز الاستقبال – ولتحليل هذا النموذج العملي قد استخدم شكلين مختلفيين من جهاز الاستقبال وتم مقارنة النتائج بينهما. لتتبع الطبق المكافئ ، يتم استخدام أربعة Light dependent resistance لاكتشاف موقع الشمس في السماء بحيث يتبعها نظام التتبع لجعل الإشعاع الشمسي عموديًا على سطح الصحن طوال الوقت خلال اليوم للحصول على أقصى طاقة شمسية. يناقش هذا العمل المراحل الأساسية لنموذج ثنائي المحاور؛ التنفيذ ، إستراتيجية الموقع الشمسي ، التحليل النظري ، التصميم الإنشائي والمواد. للنموذج الأولي ثنائي لمحور يتم تنفيذه بمساعدة Programmable logic control-Siemens (S7-1200) نتج عن هذه الدراسة أن جهاز تعقب الطبق المكافئ مع مستقبل أسطواني مخروطي يحصل على 15.25٪ كفاءة محسنة مقارنة بالمستقبل الأسطواني. وفقًا لنتائج اختبار تصميم النموذج الأولي ، فإن كلا شكلي جهاز الاستقبال مناسبان لإنتاج البخار.

الكلمات الرئيسية: مكثف حراري للطاقة الشمسية ، طبق مكافئ ، نظام تتبع ، مستقبل ، PLC.

1. INTRODUCTION

The global demand for energy, clean energy, is increasing rapidly. Protecting the environment through pollution control, particularly greenhouse gas emissions, has become a significant concern worldwide. The sun is considered the main source of energy. Sun energy is renewable energy, clean, it is available in all parts of the world, and it is not required costly and complicated technology. It can be used to produce a valuable energy source in most parts of the world. Also, countries with insufficient energy can consider the most suitable solution for development and economic growth **(Majeed, et al., 2021).**
Kurdistan region of Iraq- Erbil city is located in the sunny belt. Due to the intensity of solar radiation in Erbil city, using (a solar thermal concentrator) to generate useful energy is economically operable, and it could have significant savings in gas, oil, and electricity consumption. Moreover, solar energy is environmentally friendly and reduces emissions of CO_2 caused by fossil fuel, gas, and oil used for energy production.
Solar thermal and solar photovoltaics are two primary types of solar-energy technology. Solar energy is converted to heat via thermal collectors for solar thermal, whereas PV produces electricity directly. Higher efficiency, cheaper investment costs, and the ability to store thermal energy effectively are advantages of solar thermal energy over PV

(Savangvong, et al., 2021). Solar collectors are separated into non-concentrating and concentrating collectors. Concentrating collectors such as (parabolic dishes, parabolic troughs, and central towers) and non-concentrating like (evacuated tubes, and flat plates). Parabolic-dish reflectors are more efficient and higher efficiency when compared to other types of a collector because of the concentration the higher amount of solar energy at the tiny focal point, with a small radiation loss due to the small area of the receiver at the focal point, and components of the parabolic-dish also available and in the market, low cost in construction. But the disadvantage of this type is that two-axis tracking is required to follow the sun rays during the daytime to collect higher solar radiation by the collector **(Munef et al., 2015)**. The tracking system is separated into two types: single-axis and two-axis; two-axis tracking- system is more costly than a single-axis tracking system but more efficient and accurate. Therefore, the control unit is required for the automatic tracking system. In this study, the tracking system calculation is done with photo sensor LDR. **PLC** was used as a control unit to improve the system's performance and increase heat energy gain and collector efficiency.

(Al Hamadani, 2019) analyzed energy and exergy performance of parabolic-dish experimentally and numerically. The effect of different coil shapes (spiral conical & spiral helical) of the absorber and different mass flow rates HTF were investigated. A two-axis tracking system was used to follow the sun location. The main objective of this study was to focus on the receiver's increased energy and exergy efficiency. It minimized the difference between the wall of the absorber and the HTF temperature by designing a new shape for the absorber. The result of the experimental work showed that (the spiral helical coil) absorber had higher values of useful energy and efficiency at the lowest flow rate; also, the outlet temperature of HTF increased to a value that was enough to generate steam. **(Medina, et al., 2019)** studied the design of a parabolic-dish prototype with two-axis tracking based on proportional-integral at the National Polytechnic Institute in México. The main objective of this work is to generate thermal energy with the temperature for small, and medium industry application services like domestic uses. The two-axis tracking system was developed based on the angular relationships with a control-system proportional-integral action used to control collector motion and collect solar radiation under cloud cover or whether the collector remains oriented toward the sun rays, a tree, or a building shades it. The experimental data showed that the prototype could generate “30kg” of steam from the water heating. **(abu_mallouh, et al., 2011)** focused on the effect of two-axis tracking on the solar-cooking- system. A prototype of a solar dish was built to concentrate solar radiation on the pot that was fixed at the dish's focal point. The collector tracked the sun rays by using a two-axis- tracking system based on **PLC**. In this work, **PLC** was used to control the work of the actuator to track the sun. The electromechanical structure was used to derive a spherical-solar -cooker with the help of two motors. A spur gear is used to slow down the motor's speed and amplify the motor's torque. The experimental result shows that the temperature inside the pot reached more than 93˚c at an ambient temperature of 32˚C **(Villamil, et al., 2013).** This paper presented a prototype design of a solar dish for a rural area in Colombia that had no access to electricity service.

A polished stainless-parabolic dish was used to concentrate solar radiation to a small focus point. The energy generated was used for cooking or fulfilling a necessity in Colombia. This study was taken on structural design, thermal analysis, and manufacturing materials. A parabolic dish was used with a diameter of 1.5m. A polished-stainless steel AISI 430 BA

reference was used in the concentrator dish. The beam radiation measured in this area was 826.68 W/m². For this radiation, instantaneous thermal efficiency reached 48.5%. **(Al-Haddad and Hassan, 2011)** focused on the effect of the solar tracking system on the efficiency of the solar cells had attracted the attention of researchers recently because the attention has been directed to renewable energy sources. Both types of solar tracking systems, maximum power point tracking (MPPT) and sun path tracking were studied in this paper and a simple low-cost sun path tracking was designed using simple mechatronics with an added cost of about 15%. A design of a sun path tracking system showed that the output power of the moving PV panel increased by about 57% when compared with the fixed PV panel. **(Al-Najjar, 2013)** evaluated experimentally the PV module was carried out to evaluate the PV performance characteristics of the one-axis daily tracking and fixed system for Baghdad, Iraq. The first experiment was carried out for six months of the winter half of the year to simulate the one-axis daily tracking. The azimuth angle was due south while the tilt angle was being set to optimum according to each day of simulation. The second experiment was done on one day to simulate the PV module of fixed angles. It is found that a significant power gain, for the half-year period, of 29.6% for the tracking system relative to the fixed PV system. The obtained power gain is higher than the cost of a tracking system. The one-axis daily tracking is much more effective near winter and summer solstices as compared to other months of the year. According to the experimental work authors concluded that to increase the output power, efficiency, and fill factor of the PV module the Power conditioning system was required for load matching.
This experiment is about designing a real-type prototype for a solar parabolic dish with two axis tracking system by using **PLC** for the maximum solar power energy. These results are essential for steam generation by using clean energy and building solar thermal concentrator farms in the future in the Erbil area. This will give a comprehensive view of the installation of electrical power generation from solar thermal concentrators in the Erbil region in the near future. Solar energy is clean, environmentally friendly power generation, and the local environment is suitable for building such facilities. However, more research is necessary, and this study is about to provide it as a guide for future investments in electricity generated from solar thermal energy, it is the main objective of this study. The novelty of the current study is that the **PLC** control method has been replaced by the traditional control method which significantly improved the control efficiency of the solar parabolic dish concentrator. **PLC** can simultaneously evaluate data at a faster rate, thus increasing the efficiency of the system and resulting in its better performance.

2. DESIGN ANALYSIS FOR SOLAR DISH AND TRACKING SYSTEM

In this work, the solar dish parameter is used in high-quality, low-cost, and available in the local market. To better describe the suggested prototype design work, we must first analyze the prototype's parameters step by step. The schematic diagram of the prototype design of the parabolic dish is shown in **Fig. 1**.

2.1 Shape of Dish and Reflector Material

A parabolic dish as a concentrator is selected since it has a high concentrator. A satellite dish of 1060 mm diameter is used as a concentrator because it is inexpensive and can be found in the local market. The reflector concentrator's material significantly impacts the proportion of solar radiation that reaches the receiver.

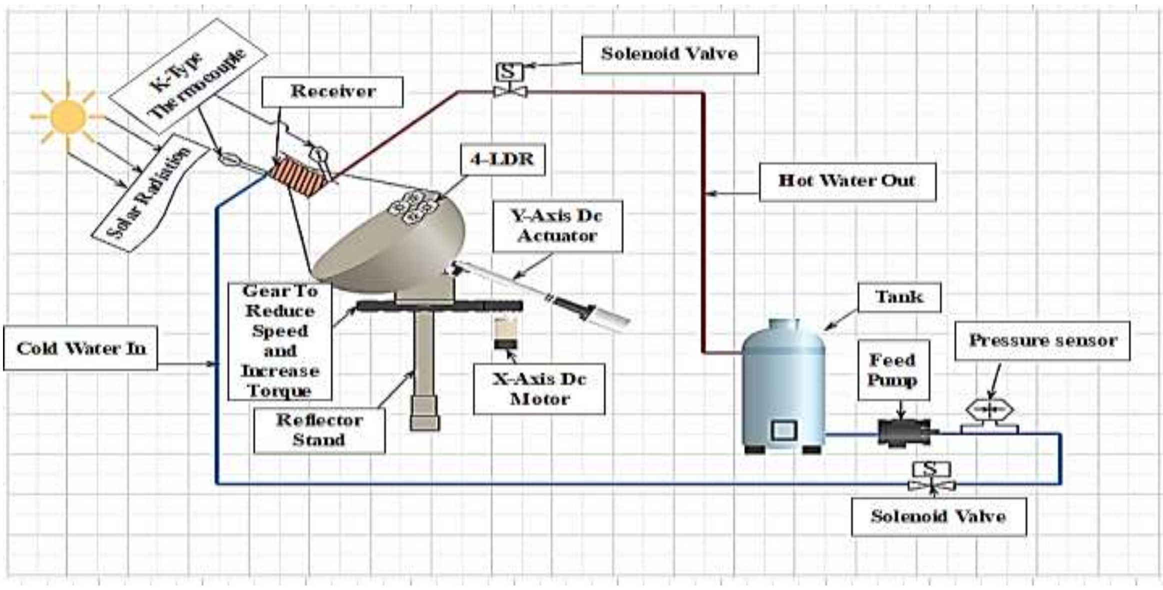


Figure 1. Schematic diagram of the parabolic dish for heating water in the receiver

An aluminum Mylar is utilized as a reflecting material in this project since it is inexpensive and readily available on the market. The Mylar film utilized has 86% reflectivity, and a 1.25 m Mylar film is used to cover the satellite dish. The dish after the reflector material has been placed on the surface as shown in **Fig. 2**.

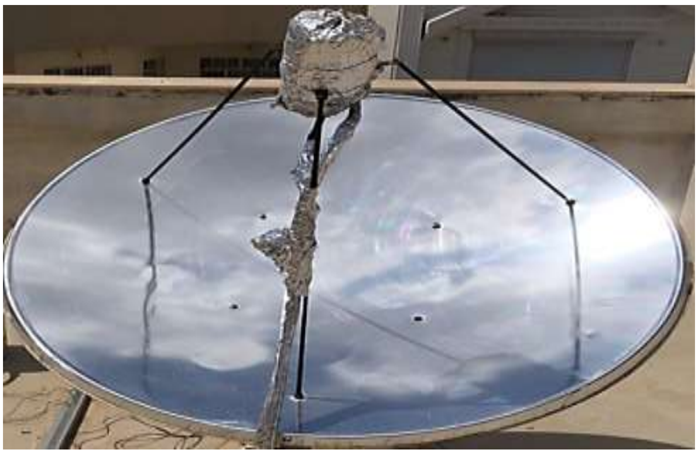


Figure 2. Parabolic dish with reflector material

2.2 Focal Length (f)

The solar parabolic dish reflector is used to reflect solar radiation to the receiver, which in turn reflect and focuses the radiations on the focal point. The focal length is the distance from the vertex to the focus. The relation between the diameter of the collector, the depth of the solar dish, and the focal length is shown in **Fig. 3**. The value of the shape factor at different rim angles and the same diameter of the concentrator is shown in **Fig. 4**; it shows that the rim angle increased when focal length decreased **(Koban and Hannun, 2021)**. The focal-length can be calculated by Eq.(1) **(Aljabair and Habeeb, 2019)**

$$f = \frac{Dc^2}{16\,h} \tag{1}$$

and f/d ratio shape factor can be calculated by Eq. (2) **(Affandi et al., 2014)**

$$\frac{f}{Dc} = \frac{1}{4\tan(\emptyset rim/2)} \tag{2}$$

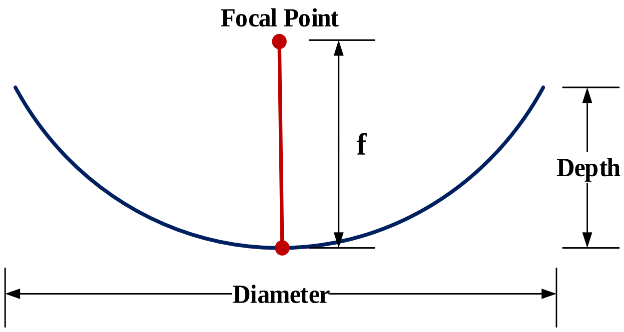


Figure 3. The segment of focal length

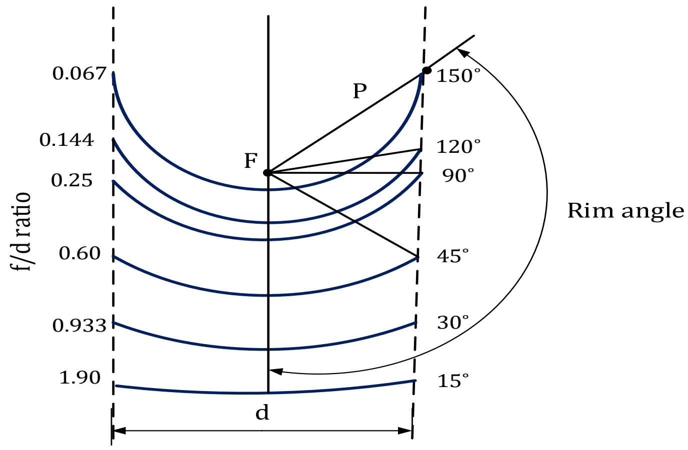


Figure 4. Relation between focal length and rim angles with the common focal point and the same concentrator-diameter

2.3 Area of the Concentrator

The area of the concentrator dish (m^2) is the total area of the solar collector surface, and also is the area that receives solar radiation. For a circular dish, the area of the collector can be found in Eq. (3) **(Aljabair and Habeeb, 2019)**

$$\text{Ac} = \frac{\pi Dc^2}{4} = \frac{\pi 106^2}{4} = 0.88m^2 \tag{3}$$

2.4 Rim Angle

The rim-angle is the angle measured at the focus from the axis to the rim of the solar parabolic-truncated. The rim angle ($\emptyset rim$) can be calculated by Eq . (4) **(Savangvong, et al., 2021).**

$$\tan(\emptyset rim) = \frac{r}{f-h} \tag{4}$$

where
r = radius of concentrator $= \frac{Dc}{2}$
h= Depth of concentrator

2.5 Receiver Diameter

The diameter of the Receiver can be calculated by Eq. (5). In addition, this factor that affected the size of the receiver, as shown in **Fig. 5** Shows the impacts of the parabolic dish's acceptance angle **(Affandi, et al., 2014)**

$$Drec = \frac{f\times\theta}{\cos\emptyset rim(1+\cos\emptyset rim)} \tag{5}$$

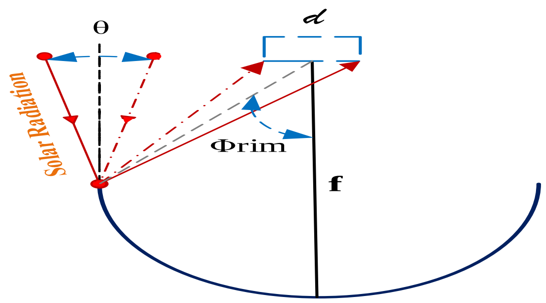


Figure 5. Relations of the receiver diameter of the parabolic dish (d=Drec) with focal point, focal length, and rim angle also with an acceptance angle

2.6 Receiver Shape

In the current project, each of the cylindrical-conical and cylindrical receivers was chosen. The cylindrical-conical receiver was selected because it has a small area facing the aperture collector, which decreases the reflection losses. Thus, this receiver design gives more chances to receive the internally reflected photons. The receiver consists of a set copper windings coil with high conductivity of 401W/m.K, a high melting point of up to 1000 °C, and a Density of 8960 kg/m^3. The copper tube is painted with high-temperature matt black paint to increase the absorptivity of the receiver. The absorptivity of matt black paint has 0.95, and the emissivity is 0.5, and the receiver was insulated with a fiberglass wool insulator with high-thermal resistance to minimize heat loss; all these parts were made locally. The shape and structure of the cylindrical and conical cylinder receiver that is designed in the current research as shown in **Figs. 6 A and B**. The structural parameters of the designed receiver are reported in **Table 1.**

(A) **(B)**

Figure 6. The shape and structure of (A) Cylindrical-conical receiver and (B) Cylindrical receiver

Table 1. The specification of the receivers.

Optimized Diameter	Receiver Type	
	Cylindrical Conical	Cylindrical
The outer diameter of the receiver (cm)	9.5	10
The inner diameter of the receiver (cm)	7.5	8
Height of the receiver (cm)	10	12
Number of tube turns at the receiver (turns)	14	15
Diameter-of the copper tube (mm)	6	6

2.7 Concentration Ratio

The concentration ratio (Cr) is the ratio of the dish area to the receiver area. It is essential find to design a parabolic dish with a concentration ratio greater than 10. Eq. (6) is used to the concentration ratio **(Savangvong, et al., 2021)** and the area of the receiver can be found by Eq. (7) **(Hafez, et al., 2016)** as follows:

$$\mathrm{Cr} = \frac{\mathrm{Ac}}{\mathrm{Arec}} \quad (6)$$

$$\mathrm{Arec} = \frac{\pi}{4}\mathrm{Drec}^2 \quad (7)$$

The geometric characteristics of the dish that it's designed in the current research, as well as optical and thermal properties, are summarized in **Table 2.**

Table 2. Properties and characteristics of PDS used

Parameter	Value
Diameter of the parabolic dish (Dc)	1.06m
Depth of parabolic-dish (h)	0.11m
The focal length of the dish (f)	63.84cm
Area of the concentrator	0.88m
Rim angle of the dish (ϕrim)	45.2°
Geometric concentration ratio (Cr cylindrical)	112.1
Geometric concentration ratio (Cr cylindrical − conical)	124.22
Shape factor f/D	0.6

2.8 Tracking System Mechanism

For the Solar dish to track the sun during the daytime, solar detectors such as (LDR) were used to detect the location of the sun in the sky and rotate the dish toward it by using a motor and actuator. LDR sensor for detecting the sun's position is the best mechanism for tracking systems because of their accuracy and cost-effectiveness. The solar parabolic dish tracking system block diagram as shown in **Fig. 7**

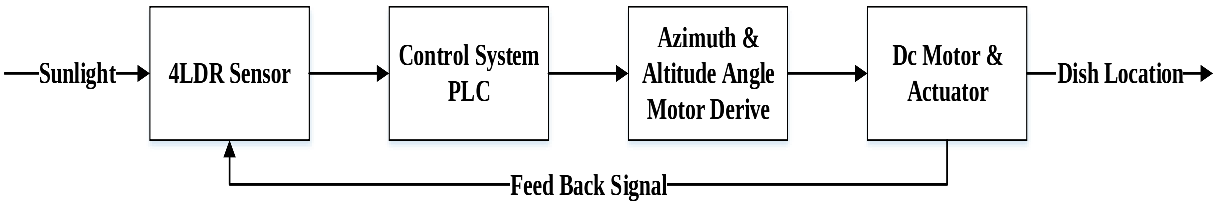


Figure 7. Tracking System Block Diagram

The slight difference between all four directions is detected using four LDRs Difference in the light intention between east-west is detected using two LDRs, whereas the difference in the light intention between south-north is detected using two LDRs. The four LDRs are attached to the frame of the solar dish tracking system **(Sinjari and Shareef, 2016).**
A Dc gear-motor 12VDC is used to rotate the dish in the east-west direction (0-360°) to follow the (Sun azimuth angle). The speed of the Dc motor is "40 rpm", it cannot be attached to the shaft directly because for azimuth angle the desired speed is 3 degrees/second, it was found from the earth-sun geometry equation; therefore, the DC motor speed is reduced to the smallest value for accurate angle by feeding the DC-gear-motor with (3v) then the speed reached to 10 rpm, and two driven gears are used, as shown in **Fig. 8**, the speed is reduced from 10 rpm to 0.59rpm, (0.59 rpm = 3.54 °/s).

$$\frac{10}{N2} = \frac{135}{8} = 0.59 \text{ rpm}$$

A DC-actuator with 12VDC is used to rotate the dish in the south-north direction (0-180 °) to follow (Sun altitude angle). A control system (**PLC**) was used to control the rotation of the two-axis tracking system of the parabolic dish depending on the 4 LDRs as input.

2.9 Mechanical Structure for Tracking System

The mechanical structure for the tracking system for the current research is built from iron pipes of different diameters to be strong enough to handle the parabolic dish in terrible weather conditions. The mechanical system is made of two parts; upper and lower parts. Two bolts and nuts connect both parts. The two-axis tracking- system mechanical structure as shown in **Fig. 8**

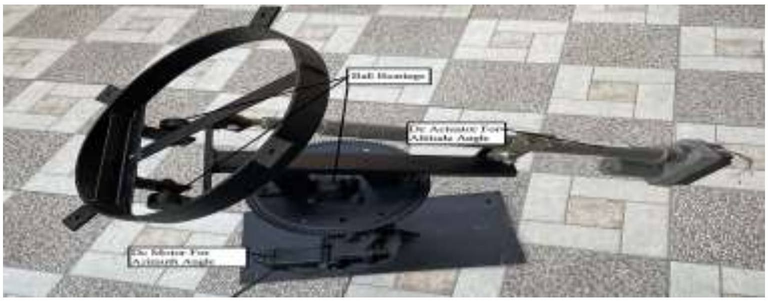


Figure 8. The mechanical structure

3. INSTRUMENT AND ERROR ANALYSIS

To study the collector thermal efficiency and power gain should record the primary data that gives an impression about the system depending on measuring tools. The first data recorded are the water temperature entering the absorber (receiver) and the water temperature exiting the absorber. Temperatures are obtained using the k-type thermocouple with a measuring range of 90 to 800) °C. They are joined with the SM 1231 Thermocouple model to record data and control the receiver's temperature. The pressure sensor (HK1100C) model with a measuring range of 0-1.2MPa is used to indirectly measure the flow rate of the water that flows from the tank to the receiver. The pressure sensor is joined with CPU 1214c DC/DC/DC analog input part as a control unit to record data like a data logger. To calculate the solar radiation that reached the collector dish pyranometer (Hukseflux LP02) is used and it is connected to data logger LI-19, which has a range between (0 to 2000) W/m^2. The digital infrared thermometer with a measured range between (-50 to 300) °C is used to measure ambient temperature, as shown in **Table 3.**

Table 3. Errors and accuracies for different measuring instruments

Instrument	Accuracy	Range	Error%
Thermocouple k-type	±1 °C	200 to 1250 °C	1
Digital thermometer	±1 °C	-50 to 300 °C	1
Solar meter	±3%	0-2000 W/m^2	1.5
Pressure sensor	±1.0% FS	0-1.2 MPa	1.5

4. THE USED PLC IN THE CURRENT STUDY

The **PLC** CPU used in the proposed work is Siemens-s7-1214 DC/DC/DC as shown in **Fig. 9,** which is part of the S7-1200 family and has the following feature:

- 24 VDC supply type.
- 14 discrete inputs 24 VDC.
- 10 discrete output 24VDC.

The used Analogue input is Siemens SM-1231 DC/DC with analog inputs 8ai, and the used thermocouple input module is SM 1231TC with analog inputs 8ai. The programming software used was SIMATIC TIA Portal V15.1, Using Ladder language.
The wiring diagram of the **PLC** input and output connection as shown in **Fig. 10**

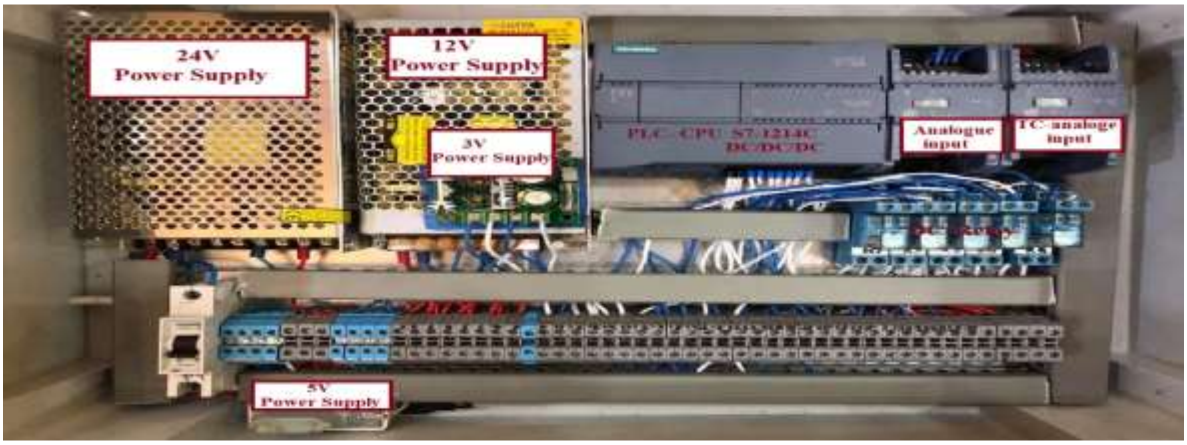


Figure 9. PLC-based control system

5. The TRACKING SYSTEM CONTROL ALGORITHM

1. In the beginning, LDR sensors are used to check the light. If it's the daytime the system operates the **PLC** and reads the LDR inputs.
2. After reading the output-voltage-value from the LDRs circuit, the LDR of the sunrise and LDR of the sunset will be compared. If the voltage output of the sunrise is more than the voltage output of the sunset by 250mv and the voltage output of the sunrise LDR is more than 500mv, then the azimuth motor rotates toward the sunrise (East) side till the difference is less than 250mv or (ELS) is closed.
3. Suppose the voltage output of the sunset LDR is more than the voltage output of the sunrise LDR by 250mv and the voltage output of the sunset LDR is more than 500mv. In that case, the azimuth motor rotates toward the sunset (West) side until the difference is less than 250mv or (WLS)is closed, then the azimuth motor stops in rotation.
4. If the voltage output of the sunset LDR is <500 mv, the difference between sunset and sunrise is <250 mv, and (ELS) is open, (WLS) is closed, then the azimuth motor returns to (East).
5. The voltage output of the (north-south) LDR will also be compared. If the output voltage of the north LDR is more than the south LDR by 250 mv and the north LDR> 500 mv,

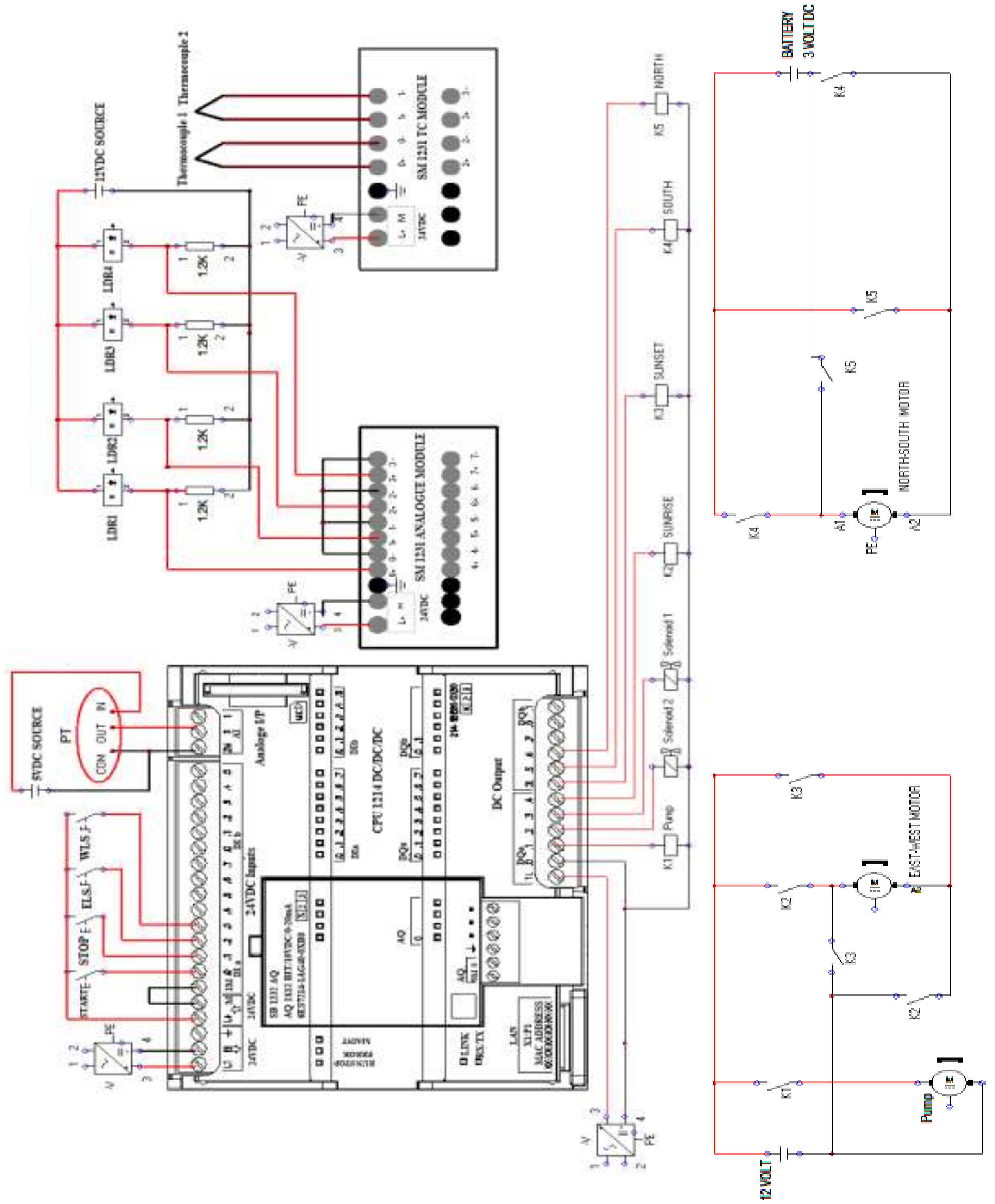


Figure 10. Wiring Diagram of the proposed work

then the actuator motor rotates toward the north side until the difference is less than 250 mv. If the south LDR is greater than the north LDR by 250mv, then the actuator motor rotates toward the south till the difference is smaller than 250mv.

6. The system checks the light via LDRs if it's not night, then the process is repeated for reading LDRs and comparing to detect the location of the sun to track the dish according to the sun position.

Each part of the experimentation work is shown in **Fig. 11**, and **Fig. 12 (A, and B)** shows the flowchart clarifies the control algorithm of the tracking system.

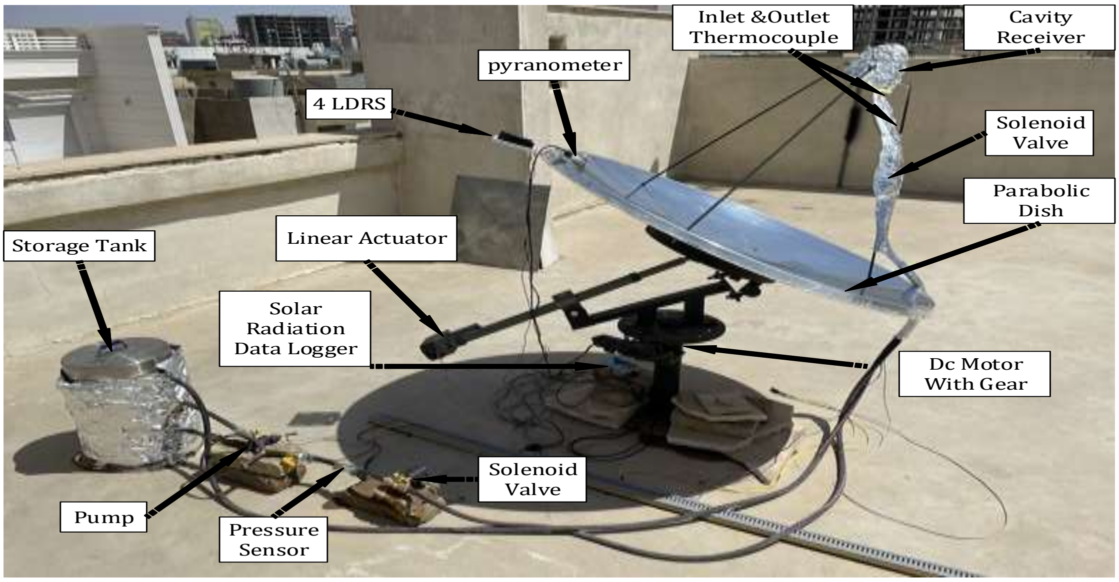
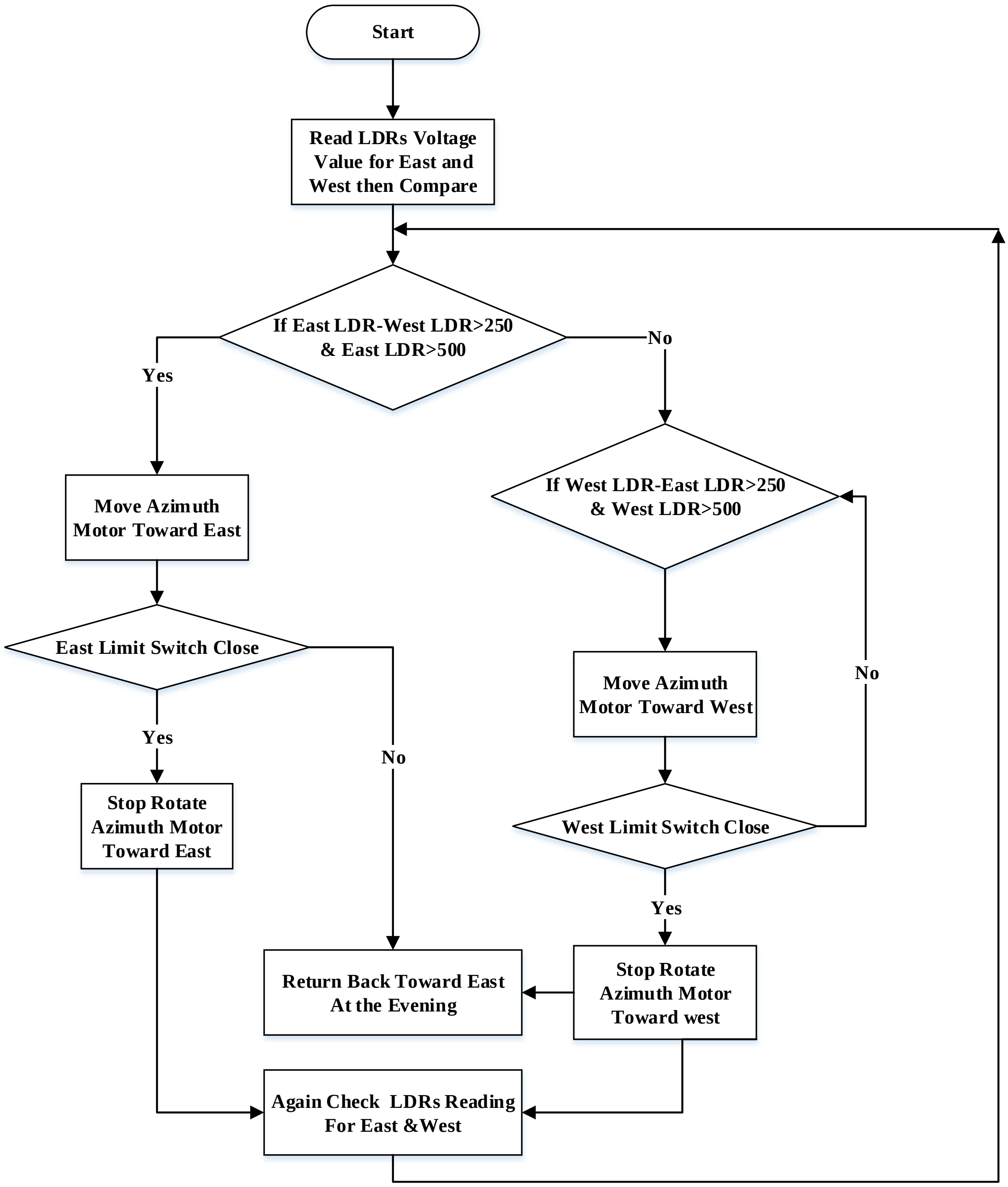


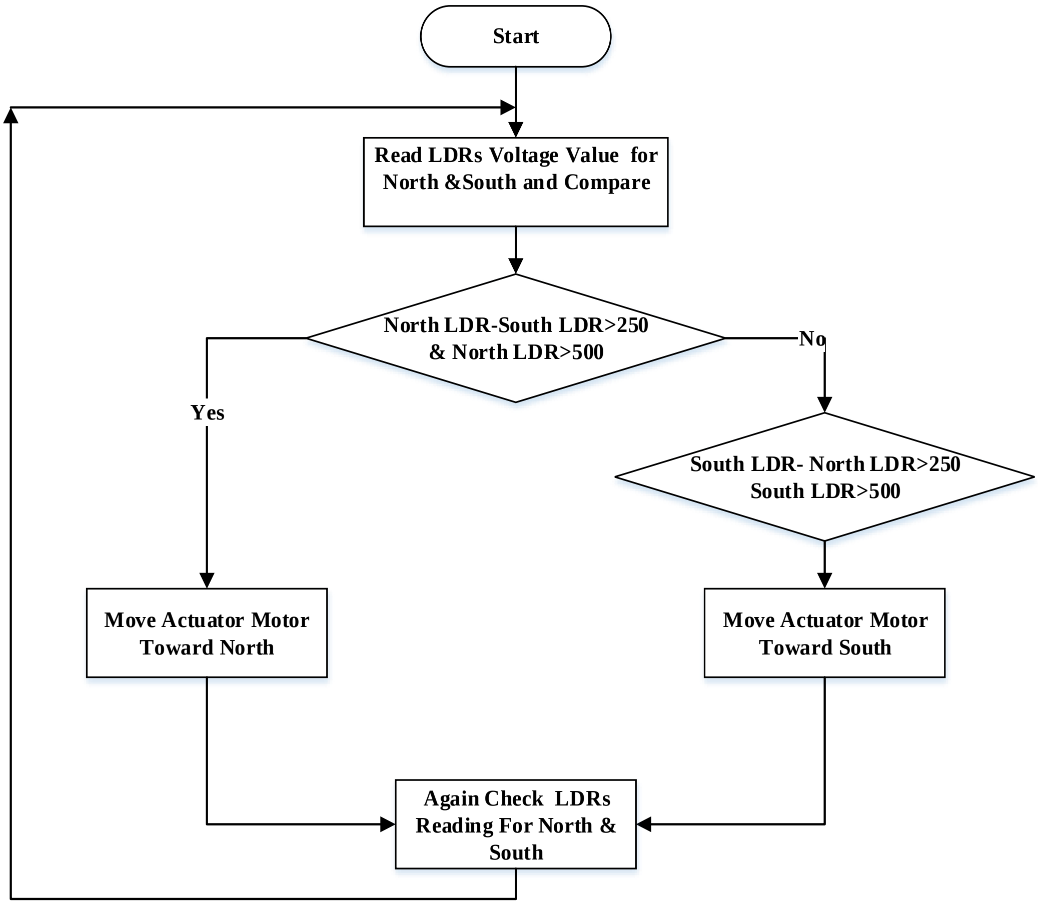
Figure 11. All parts of the experimental work

6. EXPERIMENTAL WORK

The experimentation work was performed in Erbil-city. The system is fully automatic and controlled by **PLC**. We can see the tank temperature value, output temperature of the receiver, and other values that were reached during implementation as shown in **Fig. 1**3. The parabolic dish was flowing the sun position with the help of the tracking system and **PLC**, as mentioned in section 5 tracking system, was done in both direction east-west direction and south-north direction, the center of the dish (Focal point) is directed toward the sun's position to collect maximum radiation, the cold water flow was measured by the pressure sensor, after that, the water flow to the receiver from a tank of 18 liters by using a low voltage 12 V circulating pump and by opening or closing the solenoid valves that controlled by **PLC**, the water remains in the receiver for 5 sec after that two solenoids open for 5 seconds and flowing the water between tank and boiler (receiver). This process was repeated and both inlet and outlet temperature was recorded by k-type thermocouple.



A. Tracking system for East-West Direction



B. Tracking system for North-South Direction

Figure 12. A and B The flow chart for tracking system control

7. MATHEMATICAL PERFORMANCE

The mathematical details of the parabolic dish are analyzed closely **(Wu, et al., 2010; Al Dulaimi, 2020; ALhsani and AL-Dulaimi, 2020; Koban and Hannun, 2021)**.

7.1 Optical Performance Analysis:

Many characteristics of the dish and absorber surface affect optical efficiency, including material reflectivity, absorber absorptivity and transmissivity, the factor of un-shading, and the role of incident-angle. Optical efficiency may be written as in Eq. (8):

$$\eta o = \lambda\rho\ \tau\alpha\gamma \cos\theta \quad (8)$$

where

λ is the factor of un-shading: $\lambda \approx 1$

ρ is dish-reflectance

$\tau\alpha$ is transmittance–absorptance.

γ is the intercept factor of the receiver, $\gamma \approx 1$ **(Koban and Hannun, 2021)**

(θ) is the angle of incidence.

The incidence angle of the solar beam for two-axis tracking is 0, and $\cos(0) = 1$ since the solar parabolic dish's optical axis is constantly directed towards the sun to reflect the beam radiation. So Eq. (8) can be rewritten as:

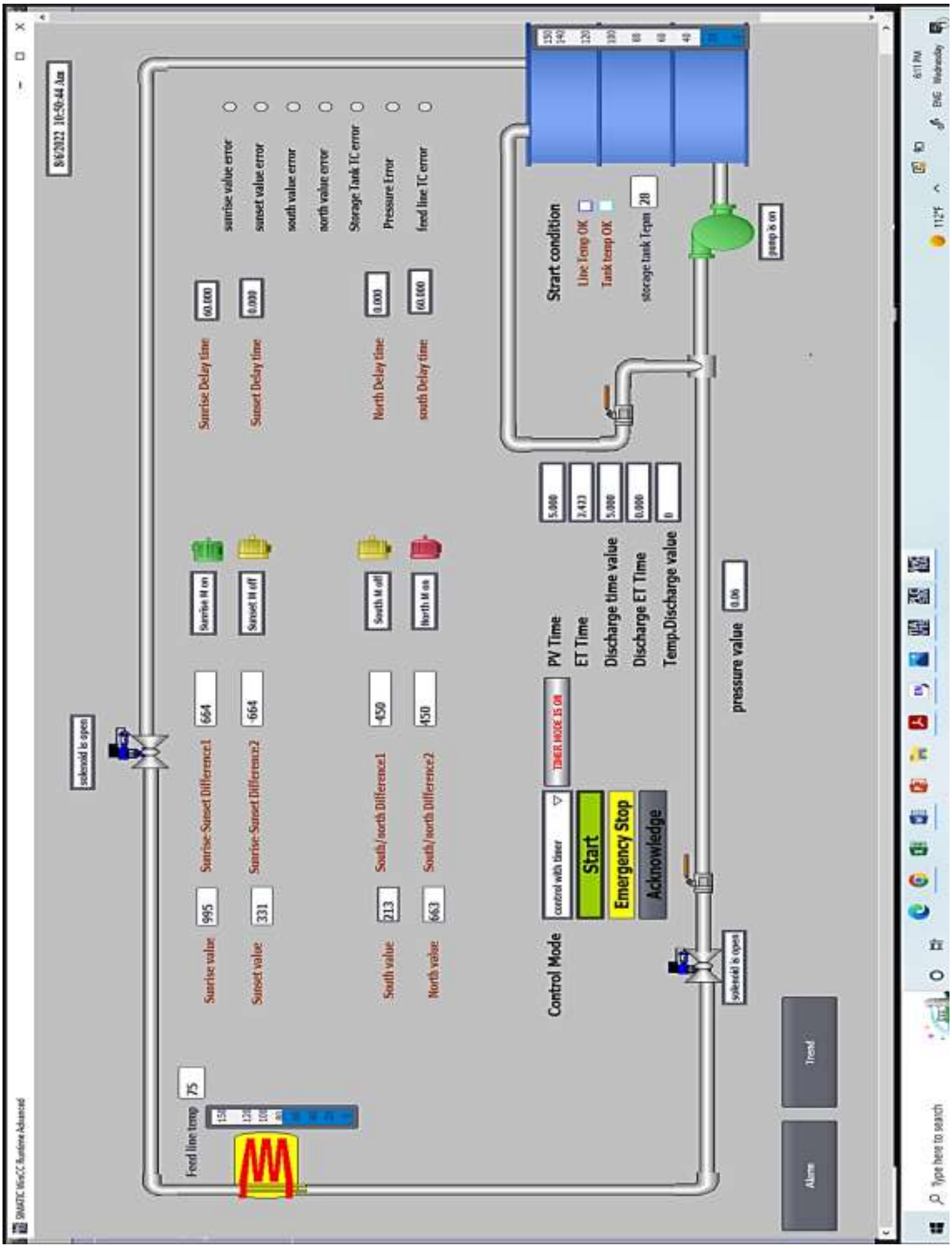


Figure 13. SIMATIC WinCC Runtime Advanced of the **PLC** program for the current project

$\eta o = \lambda\rho\, \tau\alpha,$

Mylar film was used in this work, it had a reflectance of ρ=0.86. The transmissivity–absorptivity product was $\tau\alpha = 0.95$ for matt black coating **(Wu, et al., 2010).** The optical efficiency depends on the properties of the material used, the different flaws arising from the structure of the collector, and the collector geometry. **(Al Hamadani, 2019)**

7.2 Thermal Performance Analysis

The thermal performance of the system analysis involved useful energy (Qu) which is the output energy generated in the receiver, and the beam of solar radiation that falls on the collector area of the dish (Qs) i.e input energy. The system's useful energy is evaluated as:

$$Qu = m \times cp \times (Tin - Tout) \quad in\, Watt \tag{9}$$

m is mass flow rate;
Cpis spesific heat capacity
Tin is the input temperature of the receiver also equal to the temperature of the tank.
Tout is The output temperature of the receiver
The input energy Qs can be calculated by Eq. (10)

$$Qs = Ib \times Ac \tag{10}$$

The thermal efficiency (Collector efficiency) of the system is calculated: **(ALhsani and AL-Dulaimi, 2020)**

$$\eta = \frac{Qu}{Qs} \tag{11}$$

8. RESULTS AND DISCUSSION

Based on the design configuration presented, the complete operational experimental model of solar-thermal-concentrator and control-tracking-system based on **PLC** has been designed. Two receiver shapes with the exact specifications were used to collect data. One was cylindrical and the other conical cylindrical with a two-axis-tracking system. The experimental work was done in Erbil city at (latitude 36.1901° N and longitude 43.9930° E), Iraq. The performance of the system is analyzed on a clear-sky day on June 7^{th} and 8^{th} of 2022 from morning 10 am to evening 6 pm with the cylindrical receiver and cylindrical conical receiver respectively, the weather condition is as follows: for June 7th temperature between 27C° and 41 °C, wind speed 11 km/h and humidity 15% and for June 8^{th} the ambient temperature varied between 28 C° and 40 °C, wind speed 11km/h and humidity 16%. Input temperature, output temperature, ambient temperature, and beam solar radiation are recorded. The volumetric flow rate at 0.1 L/min was maintained constant to ensure a proper reading.
The beam radiation value varies during the daytime as shown in **Fig. 14**. It increased the value from 10:00 am, and the maximum value of beam radiation achieved at noon time 1:00

pm was 928 W/m^2. After 1:00 pm, it started to decrease in value. The inlet water temperature and outlet temperature also increased with solar radiation and ambient temperature during the day; the maximum outlet temperature was reached to120 $^{\circ}$C at noon time 1:00 pm when the absorber temperature reached 300 $^{\circ}$C. The ambient temperature was 41 $^{\circ}$C for the cylindrical conical type receiver, which means that direct steam was generated for this type of receiver; after 1:00 pm the outlet temperature started to decrease slowly till 5 pm; which means that the steam can be generated due to using two-axis tracking till evening, but after 5 pm outlet temperature decreased to below 100 $^{\circ}$C due to solar radiation. The input temperature increases with increasing outlet water temperature because the system is a closed loop between the tank and the receiver. It is increasing from 23 $^{\circ}$C until it reached 80 $^{\circ}$C at 2.45 pm.

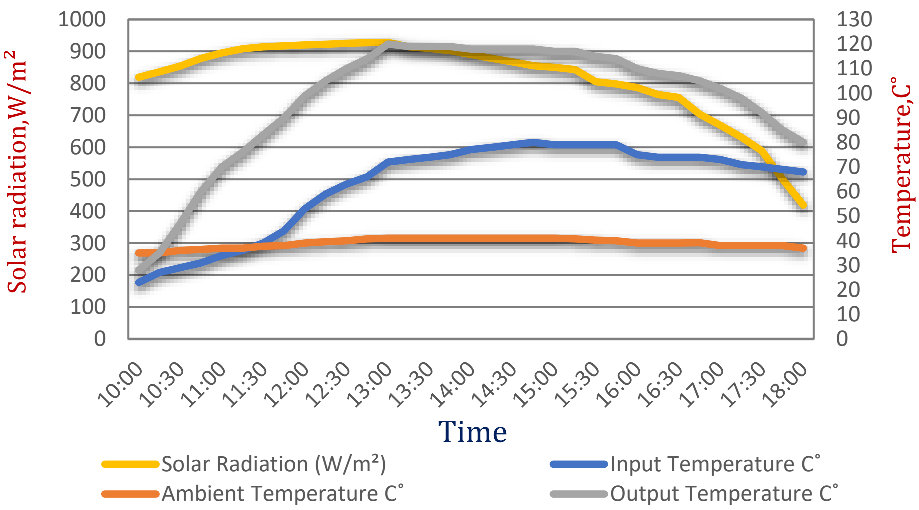


Figure 14. Beam solar radiation and temperature of the parabolic dish with the cylindrical-conical receiver (7/6/2022)

The maximum beam radiation was 933 W/m^2 on June 8th at noon time 1:00 pm as shown in **Fig. 15** according to the solar radiation outlet water temperature maximum at 1:00 pm was 108 $^{\circ}$C when the absorber temperature was 270 $^{\circ}$C and the ambient temperature was 40 $^{\circ}$C, its means that also for the cylindrical type receiver direct steam was generated till 4 pm; due to two-axis tracking, after 1:00 pm outlet temperature was decreased slowly. The input temperature increased with increasing outlet water temperature from 24 $^{\circ}$C until it reached 72 $^{\circ}$C at 3:15 pm.

Although the difference between outlet water temperatures is because two different types of absorbers are used, the outlet water temperature of the two types was high, which means that the steam was produced already. All these values along the hours of taking readings are observable in **Tables 4** and **5.**

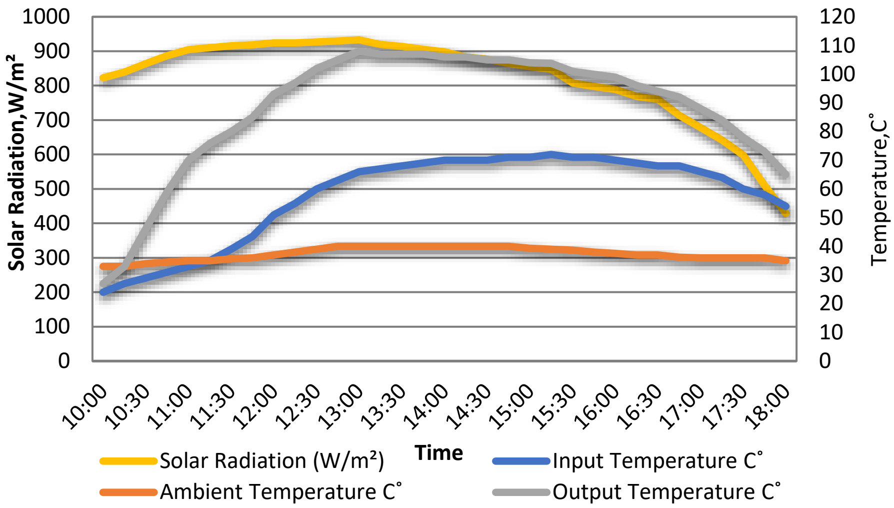


Figure 15. Beam solar radiation and temperature of the parabolic dish with cylindrical shape receiver (8/6/2022)

Table 4. Variation of inlet temperature, output temperature, ambient temperature, and beam solar radiation with cylindrical-conical shape receiver at (7/6/2022)

Time	Tin, (°C)	$Tout$, (°C)	$Tamb.$ (°C)	Beam radiation (W/m²)
10:00 am	23	28	35	819
10:30 am	29	47	36	854
11:00 am	34	70	37	895
11:30 am	39	83	37.8	914
12:00 am	53	99	39	920
12:30 am	63	110	40	925
1:00 pm	72	120	41	928
1:30 pm	74	119	41	909
2:00 pm	77	118	41	890
2:30 pm	79	118	41	867
3:00 pm	80	117	41	850
3:30 pm	80	115	40.2	805
4:00 pm	75	110	39	787
4:30 pm	74	107.2	39	756
5:00 pm	73	102	38	669
5:30 pm	70	92	38	589
6:00 pm	68	80	37	419

The valuable energy with a time of the day for cylindrical-conical receivers and cylindrical receivers with a volumetric flow rate of 0.1L/min as shown in **Fig. 16**. It shows that the valuable energy varied from 35.564 Watt to 341.41 Watt when the beam radiation varied from 819W/m^2 to 928 W/m^2 for June 7th by using cylindrical conical type receiver.

Table 5. Variation of inlet temperature, output temperature, ambient temperature, and beam solar radiation with cylindrical shape receiver at (8/6/2022)

Time	Tin, (°C)	$Tout$, (°C)	$Tamb.$ (°C)	Beam radiation (W/m²)
10:00 am	24	27	33	823
10:30 am	29	46	34	864
11:00 am	33	70	35	905
11:30 am	39	80	35.7	916
12:00 am	51	93	37	924
12:30 am	60	102	39	927
1:00 pm	66	108	40	933
1:30 pm	68	107	40	914
2:00 pm	70	106	40	898
2:30 pm	70	105	40	877
3:00 pm	72	104	39.3	855
3:30 pm	71	101	38.7	808
4:00 pm	70	99	37.6	789
4:30 pm	68	94	37	760
5:00 pm	66	88	36	679
5:30 pm	60	78	36	599
6:00 pm	54	65	35	429

On the 8th of June, the cylindrical type receiver is tested, and the valuable energy changed from 21.34 Watt to 298.74 Watt, when beam radiation is increased from 823 W/m^2 to 933W/m^2, for both types after 1:00 pm, the valuable energy was decreased gradually when the beam radiation was dropped. The result indicates that the cylindrical conical type receiver is better than the cylindrical and has increased net energy by about 14.095%.

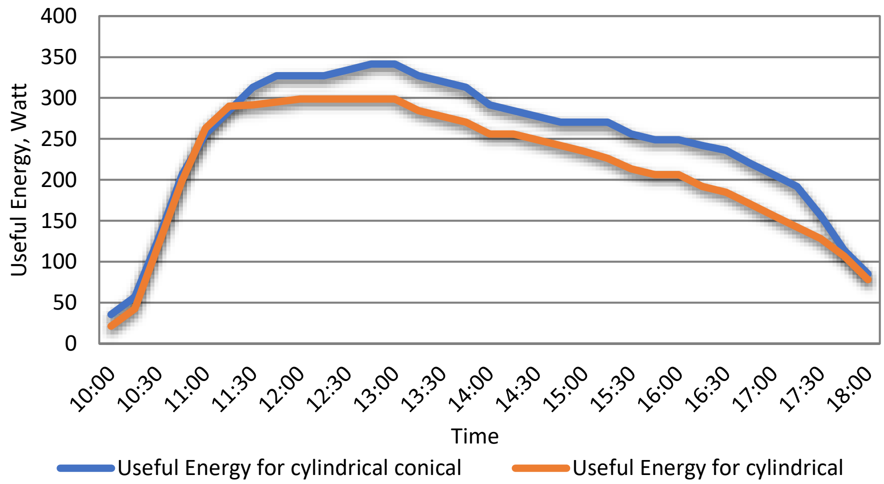


Figure 16. Valuable energy with time for cylindrical-conical and cylindrical shape receiver

The thermal efficiency of both types of absorbers is shown in **Fig. 17**. The thermal efficiency of the cylindrical conical receiver varied from 4.93% to 41.85% between the time interval (l0am-12:45 pm). The thermal efficiency of the cylindrical receiver varied from 2.94% to

36.50% for the same time interval and the same volumetric flow rate of 0.1L/min; after 1:00 pm thermal efficiency was dropped slowly till 6:00 pm approximately it has the same efficiency from 11:00 am to 6:00 pm due to two-axis tracking system maximum energy can be collected during day-time this is caused to increase the efficiency of the system. The result shows that the cylindrical-conical type's thermal efficiency is better than the cylindrical type, by about 15.25%. The variation is shown between the two receiver types, but both types generated steam with different temperatures, as shown in previous figures.

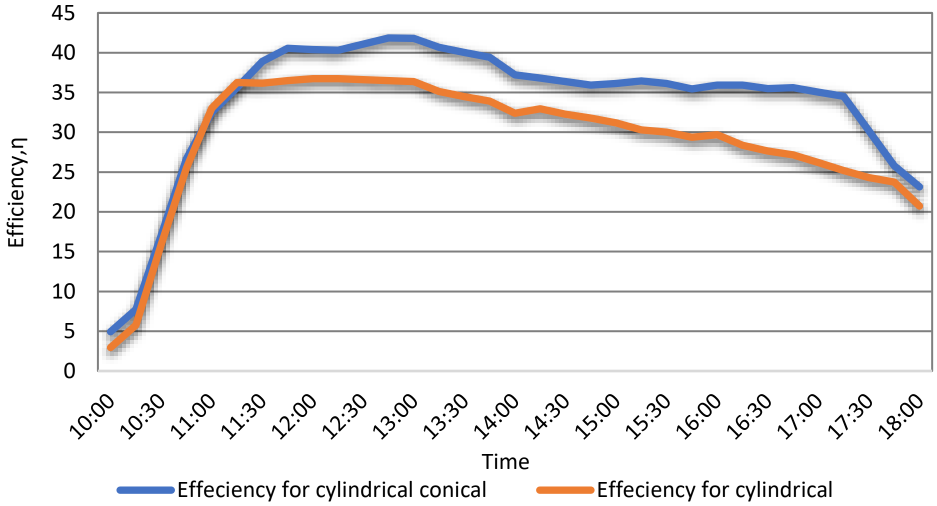


Figure 17. Variation of thermal efficiency with time for cylindrical-conical and cylindrical type receiver

9. CONCLUSIONS

The solar thermal concentrator parabolic dish with a two-axis-tracking-system was designed, fabricated, and implemented using **PLC**; the two alternative forms of the receiver were experienced; the practical results were gathered and evaluated, and the following conclusions were reached:

1. Two-axis-tracking-system was done for both types of absorbers to increase the performance of the parabolic dish.
2. The optical efficiency of the system was improved by using reflective material Mylar aluminum film with high reflectivity, and a high absorptivity receiver by painting it with high-temperature matt black paint, and (reducing heat loss) by covering it with glass wool insulation.
3. The two absorbers were compared at a flow rate of 0.1 l/min.
4. The maximum useful energy Qu for a cylindrical absorber was (298.74 Watt) and for cylindrical-conical was (341.41 Watt), which means that the useful energy for a cylindrical conical type receiver is better than cylindrical type receiver.
5. Maximum efficiency for the cylindrical and cylindrical-conical types were (36.50%) and (41.85%), which means that the thermal efficiency for cylindrical-conical type receivers is higher than cylindrical type receivers by 15.25%.

6. According to the testing results of the prototype design, both shapes of the receiver in the Erbil region are convenient for steam production; both types of the receiver are produced steam at different temperatures.

NOMENCLATURE

Symbol	Description	Symbol	Description
Ac	Area of Concentrator (m^2)	η	Thermal efficiency
Arec	Receiver Area (m^2)	ηo	Optical efficiency
Cp	Fluid-specific heat (J/kg.K)	Ørim	Rim Angle
C_r	Concentration ratio	θ	Acceptance angle
Dc	Diameter of Concentrator, m		Abbreviations
Drec	Diameter of Receiver	ELS	East limit switch (Sunrise limit switch)
f	Focal Length	HTF	Heat Transfer Fluid
Ib	Beam radiation	LDR	Light Dependent Resistance
m	Mass flow rate (kg/s)	**PLC**	Programmable Logic Control
Qs	received energy (W)	PT	Pressure transmitter
Qu	Useful energy gain (W)	rpm	Revolution Per Minute
T	Temperature (^oC)	Tc	Thermocouple
		WLS	West limit switch (Sunset limit switch)

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