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Automonitor Trough System

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Abstract

Through the past decade, Egypt has been passing by a phase of prosperity and development but with every development comes the challenges. One of the main challenges is improving the use of alternative energies in Egypt, especially renewable energies. The main problem is to find the best way to increase the share of alternative energies. In this project, implementing communicational technologies to improve the production of alternative energies was disgusted. Our choice was on Solar thermal systems the CSP (concentrated solar power) since it has been a growing industry for the last decade because it has immense potentials in terms of power production and heat applications. There are many configurations for CSP plants, but we chose the hybrid parabolic trough design. Our solution is about regulating the electricity consumption of the feedwater pump in the system by making it work periodically according to the temperature of the oil (HTF) and preventing it from working continuously which consumed higher electricity. Many real-world factors and design requirements were considered like Optical geometry, Sun tracking technologies, effectiveness. The prototype was built depending on a variety of criteria as optical geometry equations for concentration ratio that were used to come up with the dimensions of our mirror. The produced steam runs the generator and can be used to co-produce distilled water and energy. We measured the consumption of the water pump, and it was 7.728 J in 92 sec. of working time and compared it after adding our solution and it became 6.552 J and 78 sec. of working time. we concluded that by regulating the work of the water pump the overall effectiveness increased by 15.21%.

Introduction

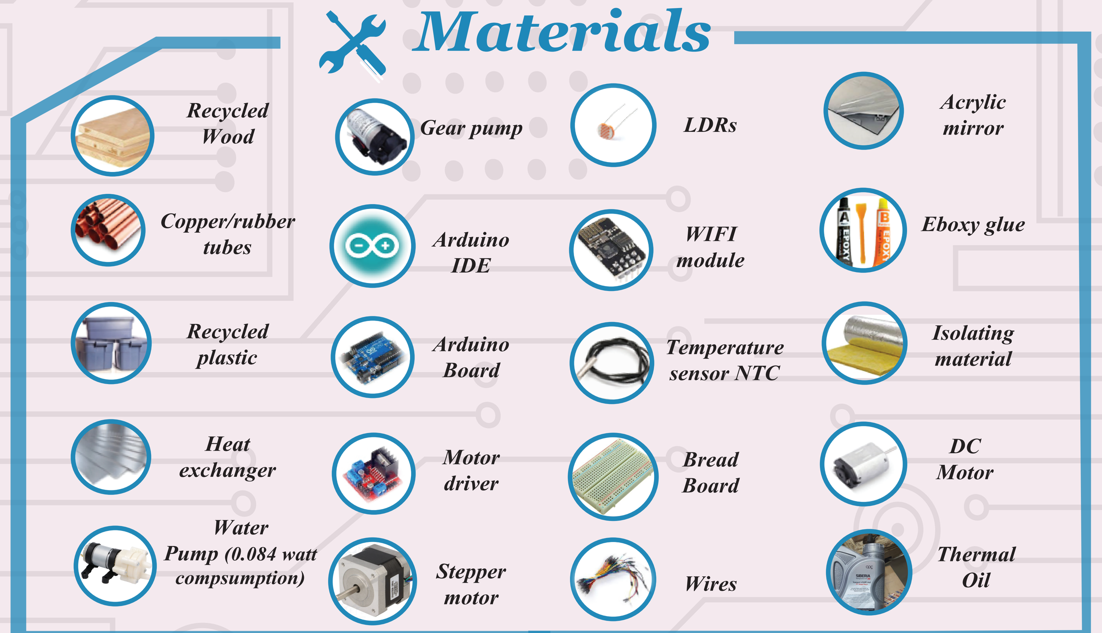
It is really fascinating how fast is the economic growth in Egypt through the past five years. However; we must consider the challenges that face the country in order to carry on this marvelous progress. One of the main challenges is enhancing the outcome from alternative energy systems using modern technologies to perform better results. Moreover; one of the promising fields in Egypt is that renewable energies which are predicted will represent about 42% of energy production in Egypt by 2035. In the capstone challenge we are asked to develop a solution that integrates communicational technologies and alternative energy systems to address a problem associated with increase of alternative energies. There are many other experiences that were conducted to solve this problem one of them was in Biogas production which was improved in India by using a web server and a website in order to monitor distribution and consumption per person and also pay bills through the internet. These techniques helped regulating production, reducing labor but it caused some problems because the website in many cases crash due to the high load of visitor per day.

Type of power station	2009/10	2021/22	2029/30	2034/35
Hydro	2.8	2.8	2.9	2.9
Wind	0.5	13.3	20.6	28.4
PV	0.0	3.0	22.9	31.75
CSP	0.0	0.1	4.1	8.1
Total	3.3	19.2	50.5	62.8

Table (1): predicts How CSP will grow till 2035

Our chosen problem will be in CSP industry. Our goal is to improve the Hybrid Parabolic trough system plant by regulating energy consumption of the system and monitoring the change of temperature of the thermal oil. CSP technologies show a promising result in Egypt it is predicted that by 2035 the capacity of CSP project will be about 8.1 GW as shown in table. (1). Our solution is all about regulating the energy consumption of the system by powering the feedwater pump in the system periodically according to the temperature readings of the Thermal Oil (HTF) using a temperature sensor. We also used a WIFI transmission in order to send data of temperature and monitor it through a mobile application. Our design requirements are firstly, effectiveness we considered (1) optical geometry to maintain the best concentration ratio for the Mirror, (2) decreasing system's electricity consumption by powering feedwater pump periodically which will cause the overall effectiveness of the system to increase, (3) Heat loss errors, (4) Sun tracking by using light sensor and stepper motor. Secondly, optimum use of material. We considered mirror material and receiver material which is the tube that receivers heat from the mirror. After doing some research for the large scale, we discovered a plant in Spain called Andasol 3 (50 MW capacity) that uses the Steam Rankine cycle and thermal oil as an HTF similar to the Kuraymat Concentrated Solar Cell (capacity of 140 MW, in Egypt). The plant's feedwater pump consumes approximately 957 kW, but with our 15.21% effective solution, the feedwater pump will consume approximately 811.44 kW. We believe that this solution will be implemented and benefit the Egyptian plant.

Materials



Methods

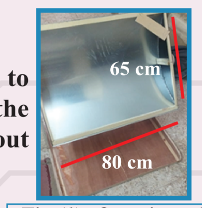


Fig.(1): Overview of prototype and mirror

Firstly, the Parabolic mirror Dimensions and construction:
The mirror dimension are 80 cm length and 65 cm width according to concentration ratio equations which is also proportional to the weight of the mirror. The reflective material will be an acrylic mirror with reflectivity of about 85% and the mirror body will be from wood.

Secondly, General overview of the prototype:
The porotype will have a base made of a thick wooden board of about (80 cm x 65 cm) and a thickness of (3.5cm). the mirror stands at a distance 15 cm from the base by two wooden columns that carry the mirror at 60 cm height. Beneath the mirror there will be all the other tanks and different stages that are in the process all standing of the wooden base of the porotype as shown in figure (1).

Fig.(2): Heat exchanger

Thirdly, The Heat Exchanger:
It is made from recycled metal at a cylindrical shape with a diameter of 12 cm and a height of 25 cm (can carry about 2826ml of water) as shown in figure (2). The oil tube was coiled as shown in figure (3) and put inside the cylinder in order to increase the surface area of the hot tubes exchanging heat with water. The cylinder will have four holes: one for the oil inlet and the other for the oil outlet, the third opening is for the steam outlet and the last one is for water inlet.


Fig.(3): Coiled tube of Oil

Fourthly, The Next Stages of the process:
Next to the Heat exchanger there will be the Steam Generator box where Steam will move a fan to generate electricity and get condensed. on the other side of the heat exchanger from the side where the oil tube outlets there will be the oil tank which is resistant to hot fluids (shown in figure (4)). There will be also the water tank near the heat exchanger which will have a water pump in it.

Fifth, Tubes and Circulations:
We used copper tubes because they are flexible and can transfer heat perfectly this can help us in coiling the tube as shown in figure (4). Tubes will be covered by an isolating material to prevent heat loss. Oil will circulate through the system using a gear pump.


Fig.(4): Stages of the prototype

Finally, is the electronic interaction and function:
First, we will put a temperature sensor on the oil tube that leaves the heat exchanger to indicate when will the oil be cold and when will it be hot in order to control the water pump and regulate the energy consumption of the water pump. Second, we will put a WIFI module that will send the temperature value regularly to a mobile app (RemoteXY) (shown in figure (5)) and help the user monitor the temperature. This will help us approach the condition of using communication in our solution. Third is the sun tracker, the sun tracker will be an independent system that uses light Arduino sensors and a servo motor to track the sun

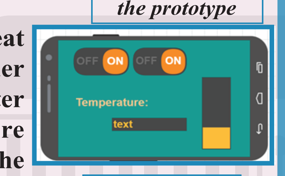


Fig.(5): Show RemoteXY

Test Plan

In the test plan we conducted three design requirements (optical geometry, system's energy consumption and sun tracking techniques)
First, Optical geometry was tested as the receiver tube at the mirror reached to 50 °C in 8 minutes and 110 in 20 minutes (due to low ambient heat in winter).
Steps of test plan:
1- The sun tracking system (LDR + stepper motor) was optimized to track the sun. That resulted in fixed and stable focal line on the pipe to heat it up.
2-We waited for the pipe until it reached 110°C then, the feedwater pump was operated and the time for its working was calculated for the 2 different configuration systems in order to apply the requirement of reducing the energy consumed.
3-In the 1st configuration (without our solution):
Firstly, the working time of feedwater pump was 92 seconds (until the boiler was filled with water).
Secondly, the condensed water was 40 ml.
Thirdly, the working time for the generator was 10 seconds.
In the 2nd configuration (with our solution):
Firstly, the working time of feedwater pump was 78 seconds (until the boiler release less vapor at 90°C).
Secondly, the condensed water volume was 35 ml. thirdly, the working time for the generator was 10 seconds.

Results

An effectiveness of 15.21% was reached by regulating the feedwater pump. The results were as follows table(2):
The time of working for the generator is the same because the steam force and velocity from the boiler is the same at the 2 systems configurations. Also, the ampere and volt are minimized because the generator is a DC motor that work against its function.

Parameter	1st configuration (before solution)	2nd configuration (after solution)
Pipes	To 110°C in 20 min.	To 110°C in 20 min. From 110 to 90 in the boiler in 76 seconds
Feedwater pump	Operates at 110°C Never stops until the heat exchanger is full with water.	Operates at 110°C Stops at 90°C
Electrical Energy consumed by feedwater pump	E_1=0.084 watt × 92 sec. = 7.728 J of electrical energy (time indicates from the begging until the water fills the heat exchanger)	E_2= 0.084 watt × 78 sec. = 6.552 J of electrical energy.
Initial Water Temp.	25°C	25°C
Generator (E) generation.	E = IVt_1 E = 0.03 A×0.68 V×10 sec. = 0.204 J of electrical energy.	E = IVt_2 E = 0.03 A×0.68 V×10 sec = 0.204 J of electrical energy.
Water distilled volume	15 ml	10 ml

Table (2): represents the test plan's results

Analysis

A 50 MW parabolic trough system Andasol 3 power plant in Spain was studied. The load data said that the feedwater pump has the highest power consumption of 957 kW. That data goes relatively for single and hybrid parabolic trough system.
A solution based on that data was made to make the feedwater pump less consumable by regulating its operation to feed water in the boiler heat exchanger Fig. (6).

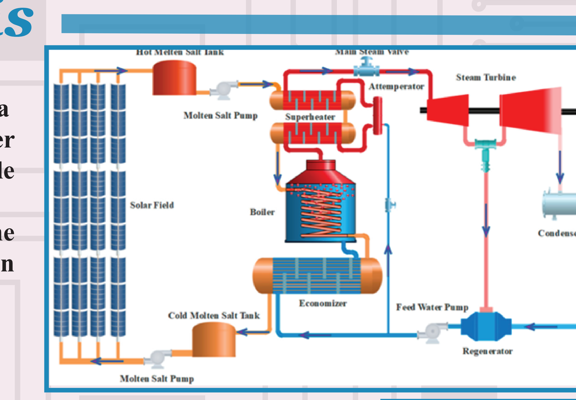


Fig.(6): Hybrid parabolic trough system

Applied design requirements:
1-Effectiveness:
1.1 System energy consumption
Since we are regulating the feedwater pump pumping into the boiler a decrease in the pump electrical energy consumption must be observed.
The power consumed by the pump is given by: P = IV (P is the power in watt, I is the current in ampere and V is the voltage in volts). Conducted from Physics (PH.2.04) Since the volt and ampere of the feedwater pump are constant and since we are regulating the pump for specific time, the time of operating has a rule to play in the calculations.
E = Pt (where E is electrical energy in joules (J), P is power in watt (J/S) and t is time of operation in seconds (s)).
Conducted from (ME.2.05)
1st system configuration (without regulating the water pump) (E1):
The electrical energy consumed is given by: E1 = Pt1
2nd system configuration (with regulating the water pump) (E2): E2 = Pt2
For calculating the effectiveness of reduction of the electrical energy consumption: Reduction effectiveness = $\frac{|E1-E2|}{|E1|} \times 100$ %
1.2 Optical geometry:
The dimensions of the mirror were conducted based on concentration ratio calculations considering its weight for the stepper motor to hold it.
Assumptions for the focal distance were made to get a reasonable width of the mirror for the best optimization of concentration ratio and the mirror weight for the stepper motor for sun tracking. The last focal distance we reached is at 16.25 cm.
For the visual representation of the parabolic trough collector (PTC), a cross-section of the PTC is illustrated in Fig. (7).

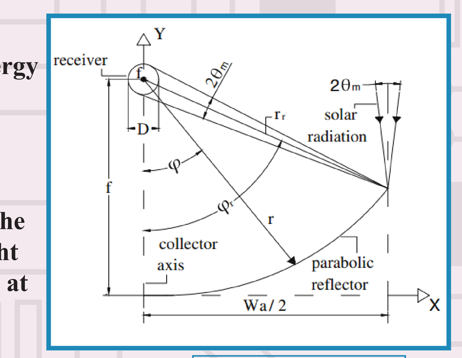


Fig.(7): illustration of a PTC (parabolic trough collector)

Some definitions:
1) F: is the focal distance of the mirror where the sun beam is concentrated.
2)rr: rim radius is the maximum mirror radius since the radius of the mirror increases as the angle between rr and F increases.
3) Φr: rim angle is the maximum angle between the rr and F.
4) Θm: is the half-acceptance angle for the perfect tracking mechanism for the sun beam. Its value is 0°16`.
5) C: is the concentration ratio. 6) Aa: aperture area of the mirror. 7) Ar: area of the receiver.
The rim radius rr is obtained from the rim angle Φr: rr = $\frac{2f}{1+\cos(\Phi r)}$ Eq 1. The maximum concentration ratio will be at Φr = 90°.
The aperture width of the parabola W is given by: W = 2rr sin(Φr) Eq 2. substitute Eq 1 in eq 2 to get:
W= $2 \times \frac{2f}{1+\cos(\Phi r)} \times \sin(\Phi r)$ W= $4f\tan(\frac{\Phi r}{2})$ Eq 3. For the perfect alignment and diameter D for the receiver pipe:
D= 2rrsin(Θm) Eq 4. The concentration ratio is obtained from: C= Aa/Ar (aperture area over the receiver area).
C= $\frac{W \times L}{\pi D L}$ so, C= $\frac{W}{\pi D}$ eq 5. . Substitute with W Eq 3 and D Eq 4 in eq 5. C= $\frac{4f\tan(\frac{\Phi r}{2})}{\pi(2rr\sin(\Theta m))}$ so, after simplifying C= $\frac{\sin(\Phi r)}{\pi \sin(\Theta m)}$
Solve for Eq 6 for maximum concentration ratio at Φr= 90°:- Cmax= $\frac{\sin(90)}{\frac{22}{7} \times \sin(0°16`)}$ =68.3.
1.3 Minimizing heat loss:
The benefit of concentration ratio:
The useful energy is given by the absorbed energy – the loss energy: using (PH.1.10) and (MA.3.01) to study the basic concepts of energy loss by convection and conduction and knowing the energy flow rate for the following equations:
Qu = Qs - QL, Qu=FR[(Gbn)(Aa)ταρ- ULAr(Tfi - Tair)]
Where FR is a term calculated for the PTC due to its geometry and the heat loss.
1) Gbn: Beam radiation on a normal surface (W/m^2) 2) Aa: the aperture area of the mirror,
3) τ: the transmittance of the glass cover. 4) α: the absorptance of the absorber,
5) ρ: reflectively of reflective material, 6) UL: overall loss coefficient calculated for each mirror. 7) Ar: receiver area,
To calculate the efficiency of parabolic trough collector:
It is given by the useful energy divided by solar energy intercepted by the collector aperture area, Sa (input energy)
Sa=Gbn×Aa
$\eta = \frac{Qu}{Sa} = FR\left[\tau\alpha\rho - Ul \times \frac{Ar}{Aa}\frac{Tfi-Tair}{Gbt}\right]$ Ar/Aa is 1/C so the efficiency equation will be: $\eta = \frac{Qu}{Sa} = FR\left[\tau\alpha\rho - \frac{Ul}{C}\frac{Tfi-Tair}{Gbt}\right]$
We can use this data to conduct that:
PTC efficiency can be increased by: 1) Using selective coating (increase α) 2) Evacuation for tubes (decrease UL)
3) Increase the concentration ratio (C) to minimize the energy loss (QL) term
1.4 Sun tracking technologies:
1.4.1 As we mentioned, we build an Arduino program to monitor the temperature using a temperature sensor and a WIFI module (using (PH.3.05) for choosing a WIFI transmission). We used RemoteXY platform to build the application. We got the code from RemoteXY platform and we used some libraries from GitHub to help us calculate the temperature and a diagram of the project is shown in figure (8)

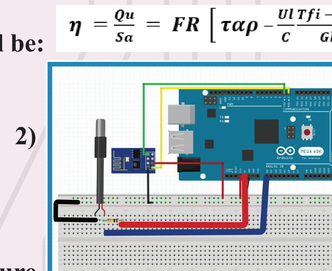


Figure (8): show a schematic diagram of the Monitoring project

1.4.2We used a Stepper Motor and light sensors to build a sun tracker. The Light sensor is put to detect in deflection in the sun's angel which will in turn signal the motor to position itself accordingly.

2- Optimum utilized materials:
2.1 Mirror reflecting material: It has been met by utilized by a 85% reflective acrylic mirror. Using (PH.3.03) for laws of reflection and determining the focus experimentally.
2.2 Receiver material:
The copper was selected as a receiver material for the pipe on the focal line because it has high diffusivity rate of heat estimated by (107 – 112 m^2/s). Also, it has the least specific heat capacity meaning that it gains heat quickly.

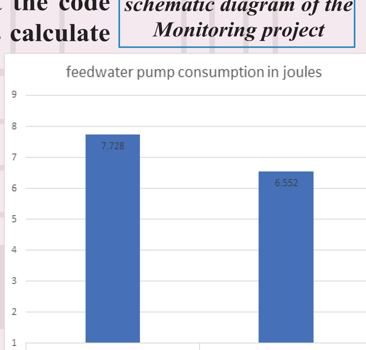


Figure (9): a comparison between the 1st and the 2nd systems in feedwater pump energy consumption

Analyzing the prototype behavior:
1- There is an electrical energy decrease in usage by feedwater pump between the 2 system configurations. A decrease of 15.21% ((E1-E2)/E1 ×100%=(7.728 - 6.552)/(7.728)×100=15.21%) fig. (10) from the non-adjusted system configuration was observed in the system where the feedwater pump is regulated.
2- There is a negative result of condensing less distilled water in the 2nd system (regulating feedwater pump) comparing it to the 1st system (with feedwater pump). Resulting in a 35 ml of distilled water produced in the modified system and a 40 ml of distilled water in the unmodified system

Conclusion

Our Capstone is to increase the utilization of alternative and clean energy by integrating Communication and technology systems. Consequently, as the Egyptian's deserts with high average temperature during daytime and sun beam radiation. So, we have chosen the hybrid concentrated solar thermal systems as an alternative clean energy source. Furthermore, working on increasing the system effectiveness by reducing its electrical energy consumption. For the system effectiveness, the reduction effectiveness for electricity consumption by feedwater pump was 15.21% with integrating the communication sensors: temperature sensor for monitoring temperature and Light sensor in sun tracking with the stepper motor in movement then showing up the statistical data on the RemoteXY application by Wi-Fi module, which is newly applied technology in solar thermal system. Thus, from the results and calculations, our design requirements were done and applicable in the real-world system. To sum up, solving Egypt's grand challenges by achieving the purpose of the Capstone and our design requirement is our duty and we must put all of our work into it to make Egypt reach the development it is seeking.

Recomendation

Since Every project has its limitations so some recommendations are needed for developments in future for both prototype and real project:
1) Firstly, to cover the copper tube by transparent vacuumed tube to prevent any heat loss by convection.
2) Secondly, utilizing a high reflecting material to collect the thermal energy from sun light without any absorption for the energy.
3) Thirdly, harness a high heat capacity transfer fluid as molten salt to maintain evaporating more amount of water in less time.
4) Fourthly, applying an Alternated current (AC) motor to increase the transmission power without wastages.
5) Fifthly, development of sensors is fundamental for instance applying high range temperature sensor and wide range Wi-Fi module.
6) Sixthly, Dryers are recommended to be presence in the boiler to filter steam from water droplets.
7) Finally, thermal storage system can be added to work the project day and night. location is important for building a real project so the consideration should be in normal beam radiation and plant location respect to the water source.
8) All the ideas above are recommended to be applied in Kuraymat Concentrated Solar Cell in Egypt same as our solution that will show perfect effectiveness of 15.21% same as what we found on Andasol 3 in Spain.

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