International Journal of Emerging Science and Engineering (IJESE)
ISSN: 2319–6378, Volume-2 Issue-2, December 2013

# Designing, Analysis and Tracking of a Concentrated Solar Power System

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***Abstract— At present, world is suffering from the biggest issue of energy. This problem can be eradicated by shifting the power generation dependency from fossil fuels to the renewable energy resources that is cost effective and environment friendly. The main idea of this research project is to collect the solar thermal resource for the purpose of power generation. This paper covers the aspects of system designing, analysis and practical implementation of the Concentrated Solar Power system. The system employs PVC mirror sheet in parabolic shape to concentrate the sun's rays onto the receiver tubes. Water present inside the Receiver tubes heated up to the exact 100°C to produce steam. Steam is used to drive conventional steam turbine which is mounted on the shaft of a generator that produces electricity. Experiment has been performed; shows that it is an effective approach of power generation but the amount of generated steam is very small. However some improvement and advancement of this system are also presented for large scale applications.***

***Index Terms— Concentrating Structure, Heat Receiver tube, Parabolic Trough Technology, Renewable energy, Steam Turbine.***

## I. INTRODUCTION

At present, one third people of the world are deprived from electricity and not linked to the national grid. In this situation, renewable energy is one possible solution. The solar power generation technology is being very popular for last two to three decades and is very feasible and beneficial resource for renewable energy. At present, the solar energy fulfils the requirements in variety of industrial and domestic use. The benefits of solar energy are enormous because of environmental protection, economic growth, employment opportunities and innovative potential for scientist and engineers. Moreover, solar energy fuel is free, abundant and inexhaustible in nature. Fortunately, Pakistan is blessed by extensive and abundant renewable energy resources of wind, hydro and solar.

There are two ways to generate electricity from the sun. First method used the concentrated solar thermal energy and the alternate method of electric generation is by means of a photovoltaic (PV) cell. In this paper, we approach the first method to generate electricity.

Manuscript received December 15, 2013.

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The three most promising ways to produce electricity through solar thermal energy are the concentrating parabolic trough, the central receiver or solar tower, and the parabolic dish. In this paper, we proposed concentrated parabolic trough consist of parabolic shaped PVC reflector sheet to concentrate sun's rays on to the receiver tubes which heat up the water present inside it up to 100°C, this heated water then converted into steam which is used to drive a turbine mounted over DC generator to produce electricity. Afterward DC output of the generator is converted into 220V AC by using inverter. The solar tracking system is employed with the concentrating collector unit in order to receive utmost energy gained by the solar system.

## II. SYSTEM DESIGN OF CONCENTRATED SOLAR POWER SYSTEM

Solar collector is the fundamental unit of the Concentrated Solar power system. Solar collector captures incident solar radiation energy. Concentrating collectors use large reflectors to ´concentrate´ the incident solar energy onto a smaller receiver. This help to increase the temperature of the heat collected from the sun. Increased temperature is directly related to the efficiency of electricity production by thermal source. The assembly of a concentrating collector is shown in Figure 1.

Parabolic trough-shaped mirror reflectors are used to concentrate sunlight on to thermally efficient receiver tubes placed in the trough's focal line. Water is circulated in these tubes, which heated to approximately 100°C; this heated water is then converted into steam. The steam is eventually converted to electrical energy by a steam turbine generator.

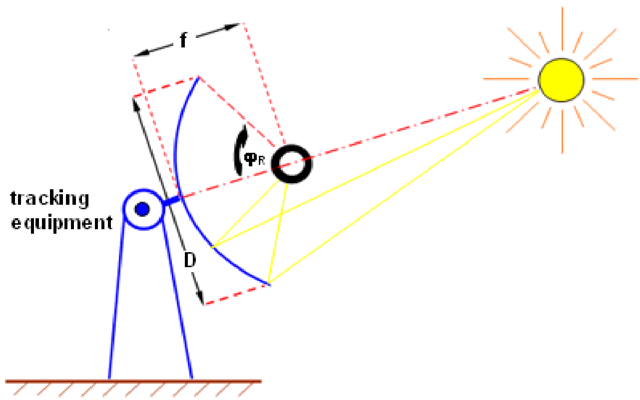


**Figure 1. Assembly of a concentrating collector**


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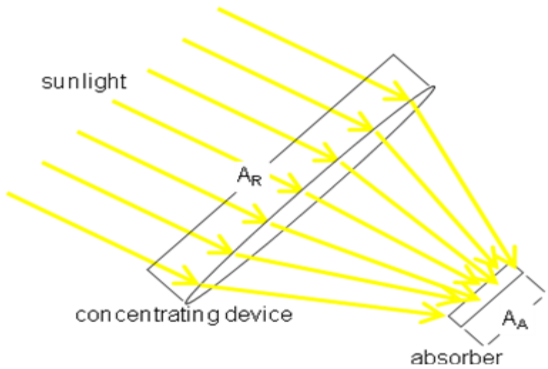


**Figure 2. Concentrating device and absorber**

The process temperature that can be achieved is dependent on the power density in the focus and it is limited by:

- divergence of the solar radiation ($a_D$=32´)
- geometry of the optics (focal point, focal line, other kind of focal area)
- precision and quality of the (real) Optics

$$C = \frac{Aperture.area.of.the.optics}{area.of.the.focus.in.the.focal.plane} \tag{1}$$

Usually in the focal plane there is an absorber, which is adapted to the size of the focus. So C is usually approximated by:

$$C = \frac{Aperture.area}{Absorber.area} = \frac{A_R}{A_A} \tag{2}$$

The entire system is divided into the following three independent sections:

I. Solar Collector Unit
II. Electric Control Circuitry
III. Power Generation

## A. Solar Collector Unit

A Solar Collector unit comprises of two elements. One is parabolic trough and another element is called heat receiver. A typical design of solar collector unit is shown in Figure 3.

*1) Parabolic trough*

A parabolic trough is simply a linear translation of a two-dimensional parabolic reflector; due to this reason the focal point becomes a line. These are often called line-focus concentrators. A parabolic trough is used to concentrate sun rays onto the receiver tube. It is constructed in parabolic shape, upon which a receiver tube is fixed at the focal point. PVC mirror sheet is used as reflector; the sunlight is reflected and concentrated through it on receiver tube, which heats up the water circulating in this tube, to convert it into steam. The trough is move on bearings, fixed on its both ends and it rotated to track the sun through electrical linear actuator when it receives a signal from control unit.

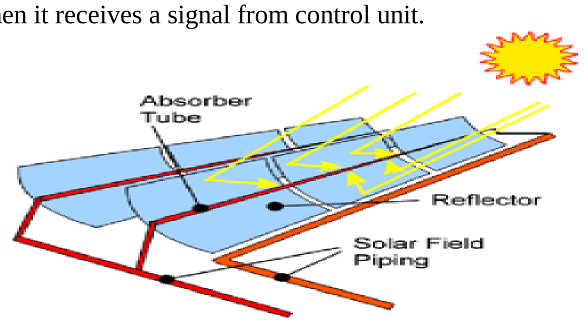


**Figure 3. Solar collector unit**

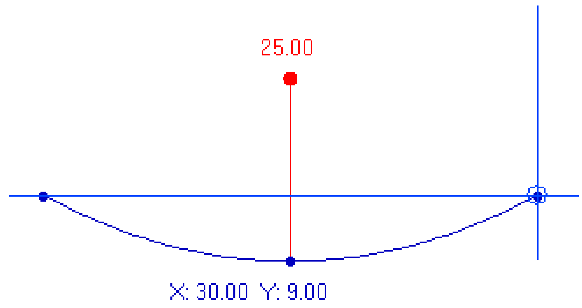


**Figure 4. Parabolic design obtained through software**

The design of parabola is shown in Figure 4. This is a standard and efficient design which reflects the maximum sun rays onto the receiver tube.

$$y = \frac{1}{4d}x^2 \tag{3}$$

On behalf of the calculation and software design visualization of Figure 2, it is adopted for this prototype model. The specification of parabolic trough design is shown in Table 1.

*2) Receiver tube*

Another major element of the collector unit is called receiver tube or heat receiver. This receiver plays a very significant role of heat absorption. The designing of receiver is the most sensitive part of the system because the whole efficiency is based on amount and pressure of generated steam through it and the steam generation is proportional to the heated water due to the concentrated solar incident energy onto the receiver tube. Receiver tube is place at focal point in the middle of the concentrating structure and carries water in it. Receiver tube is made up of aluminum pipe (tube) enclosed in a transparent glass tube with a sufficient vacuum space between them. Both tubes are sealed. The Specification of receiver tube is shown in Table 2.

**Table 1. Parabolic trough design parameters**

| S.No. | Parameter | Length(inches) |
|---|---|---|
| 1 | Diameter | 60 |
| 2 | Linear diameter | 63.41 |
| 3 | Focal length | 25 |
| 4 | Depth | 9 |
| 5 | Vertex | (30, 9) |

**Table 2. Receiver Tube design parameters**

| S. No. | Parameter | Length (inches) |
|---|---|---|
| 1 | Length | 60 |
| 2 | Inner Aluminum pipe diameter | 1.5 |
| 3 | Outer glass tube diameter | 2 |

A receiver tube should have the following characteristics for the efficient conversion of fluid into steam:

- Inner tube is of metal coated with special solar-selective absorber surface for better absorption of solar heat.

- Outer glass tube is of borosilicate material and it should be maximum anti-reflective to solar transmittance.
- There should be a vacuum space between the outer tube and inner tube to eliminate the heat losses caused by conduction and convection of both tubes respectively.
- The receiver tube should have glass-to-metal seals to achieve the necessary vacuum-tight enclosure.

### B. Electronic Control Unit

All sub-circuits of the entire control system are centrally controlled with microcontroller. All the sub portions of the entire circuit are intelligently interfaced with each other according to the given conditions of the operation time. All the controlling strategy is adapted by software only; while the hardware setup remains the same. The block diagram of the overall electronic control system is depicted in Figure 5.

The overall electronic control of this system has the following components;

- solar tracker circuit
- linear actuator control circuit (H-Bridge)
- trough position detection circuit
- temperature measurement circuit
- LCD Interface Unit

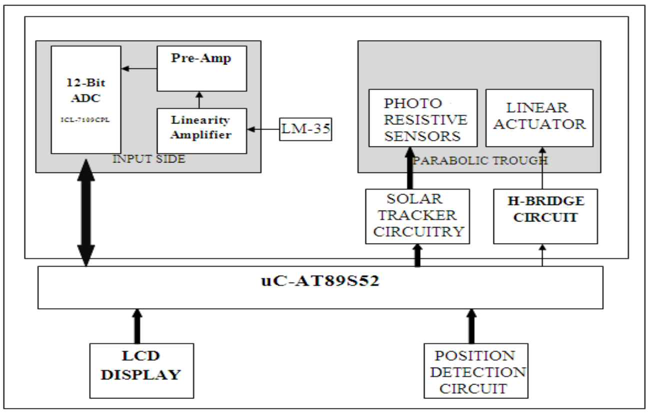


**Figure 5. Control system block diagram**

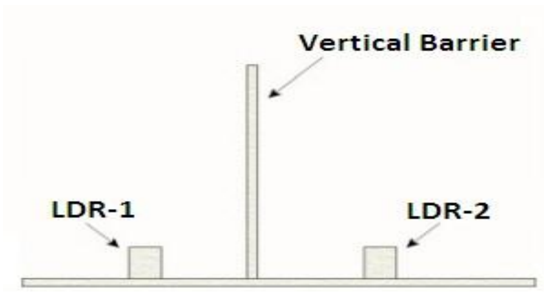


**Figure 6. Photo resistive cells alignment**

Among all the components, Solar Tracker and H-Bridge are the most important circuitry parts whose behaviour affects the overall efficiency of the system.

*1) Solar Tracker Circuit*

Solar tracker circuit is one of the key features to maximize the efficiency of this system. Vertical single axis tracker (VSAT) circuit is employed in this project; the axis of rotation for VSAT is vertical/perpendicular with respect to the ground. These types of trackers rotate from SOUTH-EAST to NORTH-WEST over the course of the day. Vertical barrier is used between two photo resistive cells pointed directly at the sun. Both cells will see the same amount of light; as the sun moves, the vertical barrier will cause the shadow on one of the photo resistive cell, which imbalance the resistance of the photo resistive cells. This imbalance is detected and a signal is generated at µ-controller to rotate the trough until both the photo resistive cells see the same amount of light once again. The alignment of the photo resistive cells is shown in Figure 6.

The solar tracking circuit is implemented by using comparator ICs(LM-339). Equation for the output response of this comparator is:

$$Vout \leq Vcc \quad \text{when} \quad V+ \geq V- \text{; else} \qquad (4)$$

*2) H-Bridge Circuitry*

The H-BRIDGE circuit is responsible to control the linear actuator in both inward and outward direction. The H-BRIDGE is used to drive high current DC motor in both forward and reverse directions.

*3) Temperature measurement circuit*

The temperature measurement circuit is used to measure the temperature of the inner tube. This circuit consist of two basic components; ADC and temperature sensor. The ADC-ICL7109CPL is used for analogue to digital data conversion for the purpose of µ-controller interfacing and LM-35 temperature sensor is used due to its cost effectiveness.

*4) Trough position detection*

Trough position detection circuit is based on simple IR transmitter receiver circuit to detect the position of the trough. The position of the trough is displayed on LCD in the form of degrees.

*5) LCD display*

The LCD is used to display the temperature of the inner tube and the position of the trough. It continuously displays all these parameters while the trough is tracking the sun.

### C. Power Generation

*1) Rankine cycle*

Rankine cycle is a heat engine that produces 'work' from heat by wasting a fraction of heat input to a low temperature reservoir. Rankine cycle is the standard cycle for steam power plants. The Basic Rankine power cycle is depicted in Figure 7. It comprised of four internally reversible processes which are described as under:

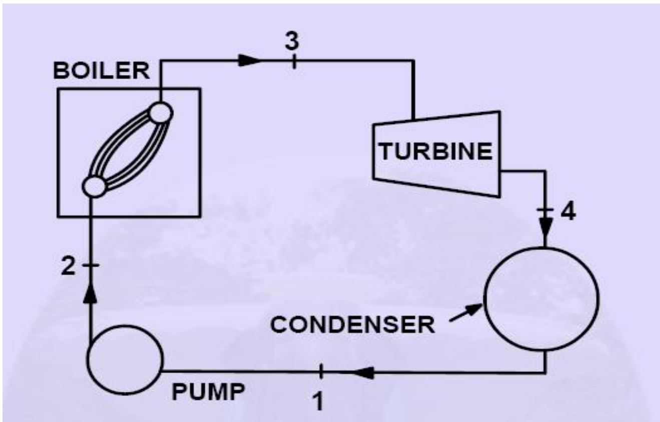


**Figure 7. Rankine vapor power cycle**

*a) Pump (Process 1-2)*

Water from the condenser at low pressure is pumped into the boiler at high pressure. This process is reversible adiabatic.

*b) Boiler (Process 2-3)*

Water is converted into steam at constant pressure by the addition of heat in the boiler. The generated steam from the boiler may be dry and saturated, wet or superheated.

*c) Steam turbine (Process 3-4)*

Steam turbines used to convert the energy stored in the form of steam into rotational mechanical energy. Superheated steam with high pressure is required to run the turbine. This steam enters in the steam turbine throttle, where it powers the turbine and its linked mechanism of generator to produce the electricity. After the reversible adiabatic expansion of steam in the turbine, it exits the back end of the turbine.

*d) Condenser (Process 4-1)*

Heat exchangers are devices built for efficient heat transfer from one fluid to another. First law of thermodynamics is applied to heat exchanger, working at steady-state condition. The recuperative type of heat exchanger may be designed with counter-flow phenomena. This is the most efficient design because it transfers the greatest amount of heat. In counter-flow heat exchanger, fluid flows in the opposite direction. If the specific heat capacity of the fluid is constant, then the heat transfer can be calculated by using the following equation.

$$Q = UAT \log mean \tag{5}$$

**Table 3. DC generator specifications**

| PARAMETERS | VALUES |
|---|---|
| Output voltage | 12 volts |
| Electrical power | 120w |
| Efficiency | 72% |
| Speed Torque | 0.46N.m |
| No Load RPM | 2850 |
| Loaded RPM | 1900 |

**Table 4. Inverter characteristics**

| Input Volt | Input Amp | Power Consume | Power Deliver | Efficie ncy |
|---|---|---|---|---|
| 12 Volt | 1.6 Amp | 19.2 Watt | 15 Watt | 78.12 % |

Where,
Q=Rate of heat transfer between two fluids
U= Overall heat transfer coefficient
A= Area of the tube
T= Logarithmic mean temperature difference.

*2) Generator*

The generator is used to convert the mechanical power into electric power. The DC power generator is used in this system because DC power source can be stored very easily for the future use, while the AC power storage is very expensive and complicated. The components of DC generator are exactly the same as the DC motor such as; the coil, split ring, brushes and magnet, but the coil is being turned, which generates an EMF. The specification of the DC generator is shown in Table 3.

*3) Inverter*

The Inverter is used to convert the DC power into AC power. The transformer is the most expensive part of this device. In the circuit, the MOSFETs are configured as bridge circuit in order to alternate current flow through the primary windings of the transformer. This circuit will supply a very stable "Square Wave" output voltage with frequency of 50Hz. The power specification of Inverter is shown in Table 4.

*a) Power analysis*

The power analysis has been conducted for the generated amount of power with the available size of the parabolic trough. The calculation of the system is performed by using the NOAA data. According to the data, a parabolic trough concentrator is capable to generate 260 W/ (m *m). The complete equation for the power calculation also contains the specification of the reflecting material which is stated as under;

$$Power_{required}(W) = \frac{Width(inch)}{\frac{m^2}{260W} * \left[\frac{1.(inch)}{Thickness.(inch)}\right]^2 * \frac{1}{length.(inch)} * R.eflectivity} \tag{6}$$

Where,
Width= Width of parabolic trough = 60 inch
Length=length of the receiver tube (parabolic trough) = 60 inch

Thickness= Thickness of reflecting material = 25 microns
Reflectivity= Reflectivity of the reflecting material = 96%

It is obvious from the above data that the length of parabolic trough is same as the length of the receiver tube. The calculated power with the above mentioned data is approximately 585W. In general purpose estimation, other factors can be neglected and power can be calculated with equation 260 W/ (m*m). By general purpose approximation, the estimated output power is approximately 600W.

## III. RESULTS AND DISCUSSION

This section reveals the result of the proposed system for power generation via solar thermal energy. The prototype model for the proposed system, named as "concentrated solar power system" has been designed with the help of proper calculated data in order to maximize the reflections of the sun rays onto the receiver tube. Afterward the completion of the system hardware setup; the software algorithm is developed to control the solar tracking system. The complete system design analysis and its power generation in different segments of the running day have been presented in this section.

Solar tracker circuit is tested in different Atmosphere conditions. It is working perfectly according to our consideration.

The graph shown in Figure 8 illustrates the response of the solar tracker in different conditions in comparison with the rotation of the sun with respect to time.

This graph shows that the system will work well on sunny day while during cloudy intervals; the tracker circuit senses no difference in the light. During a rainy day, the circuit senses the fake imbalance of light.

The steam is generated by the concentrated collector. However this generated steam does not have the sufficient pressure to drive the turbine properly. The estimated output power of the Inverter is 120 watt that's why the transformer used must be capable to handle high current up to 10 Amps. The calculated power of the proposed system is between 500w to 600w, but due to low current rating transformer of an inverter circuit, the dummy load of only 30W is tested. It has been observed that the system is working well in the tested load capacity. Its efficiency for the backup power generation becomes high on a sunny day while average in the different atmospheric conditions. Its efficiency directly affected by the atmospheric conditions under solar tracking system.

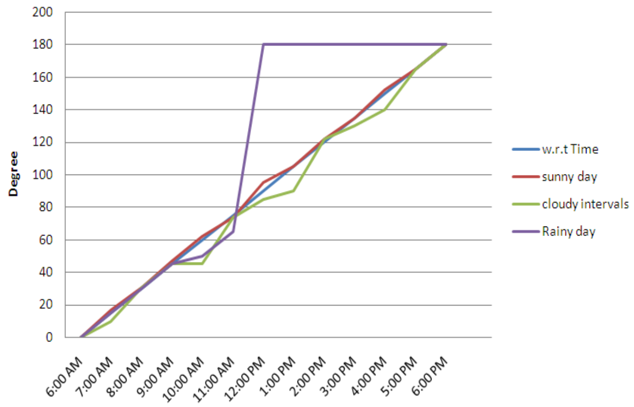


**Figure 8. Sun tracking observation graph**

## IV. CONCLUSION

The approach of solar thermal energy generation by steam turbine generator is practically very effective. The observed results validate this prototype model for concentrated solar thermal power generation system. This procedure of solar thermal power generation system has much better tendency for the large scale energy production and has a good potential for further improvement in the quality power generation and energy storage system. The power generation is affected by many factors like intensity of sun, humidity, receiver tube efficiency, surface of reflecting material, turbine losses etc.

## FUTURE SCOPE

The estimated results are effectively achieved up to some extend within the given environmental conditions. However, many advancements and improvements can be made in various aspects of this prototype model. Some suggestions and recommendations are listed below.

A more efficient methodology can be used for improved pressurized steam generation.

- Finest reflecting material with better characteristics can be used to achieve maximum solar rays concentration, which may offer utmost solar energy.
- More sensitive material should be used for the purpose of heating tube.
- Proper catalyst substance can be added into the water to low down the boiling point for the purpose of steam generation.

Effective measures should be taken in order to minimize the losses of the concentrating collector.

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