MEASUREMENT AND CONTROL OF PRESSURE AND SUN TRACKING IN SOLAR THERMAL POWER PLANT

Dhaval Patel
B.E., DDIT, India, 2006

PROJECT

Submitted in partial satisfaction of
the requirements for the degree of

MASTER OF SCIENCE

in

ELECTRICAL AND ELECTRONIC ENGINEERING

at

CALIFORNIA STATE UNIVERSITY, SACRAMENTO

SPRING
2010

MEASUREMENT AND CONTROL OF PRESSURE AND SUN TRACKING IN SOLAR THERMAL POWER PLANT

A Project

by

Dhaval Patel

Approved by:

____________________________________, Committee Chair
John Balachandra, Ph.D.

____________________________________ , Second Reader
Fethi Belkhouche, PhD.

____
Date

Student: Dhaval Patel

I certify that this student has met the requirements for format contained in the university format manual and that this project report is suitable for shelving in the library and credits to be rewarded for the Project.

___________________________ , Graduate Coordinator __________________

Preetham B. Kumar, Ph.D Date

Department of Electrical and Electronic Engineering

Abstract

of

MEASUREMENT AND CONTROL OF PRESSURE AND SUN TRACKING IN SOLAR THERMAL POWER PLANT

by

Dhaval Patel

To design a circuit that measures and controls the pressure of the generated steam to the required level. Also, that keeps track of sun path to get maximum exposure of sunlight and thus getting optimum energy level from solar radiation. This system has main components like pressure sensor, Data Acquisition System (DAS), Control Valve, water Reservoir, Steam Turbine, Water Inlet and Sun Tracking Circuit.

____ , Committee Chair
John C. Balachandra, Ph.D

____
Date

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Chapter 1

INTRODUCTION

In today's time scarcity of energy resources is the burning problem. Because of extensive use of non renewable resources demand has arouse to use the natural methods to create energy or using the renewable sources of energy to protect the extinct of energy resources and also help in reducing various types of pollution (mainly air and water pollution). This project is targeting to the use of one such renewable method. The project is about generation of power via establishing the solar power plant in California (concentrated in the Redding area), thus providing the energy to near locations for household purpose.

1.1 Need of Solar Energy Utilization

Looking at the present stock of the non-renewable energy resources like coal, gasoline and other petroleum products, utilization of renewable energy resources will become inevitable in near future. The best possible option is utilization of solar energy as it is available in abundant quantity.

Moreover, the prices of gasoline and other petroleum products are hiking day by day.

There are many surveys showing how much prices for gasoline and other petroleum products have gone high since recent years. One of such survey done by United States

Energy Information Administration is shown as follows which supports the hike of fuel prices since last few years.

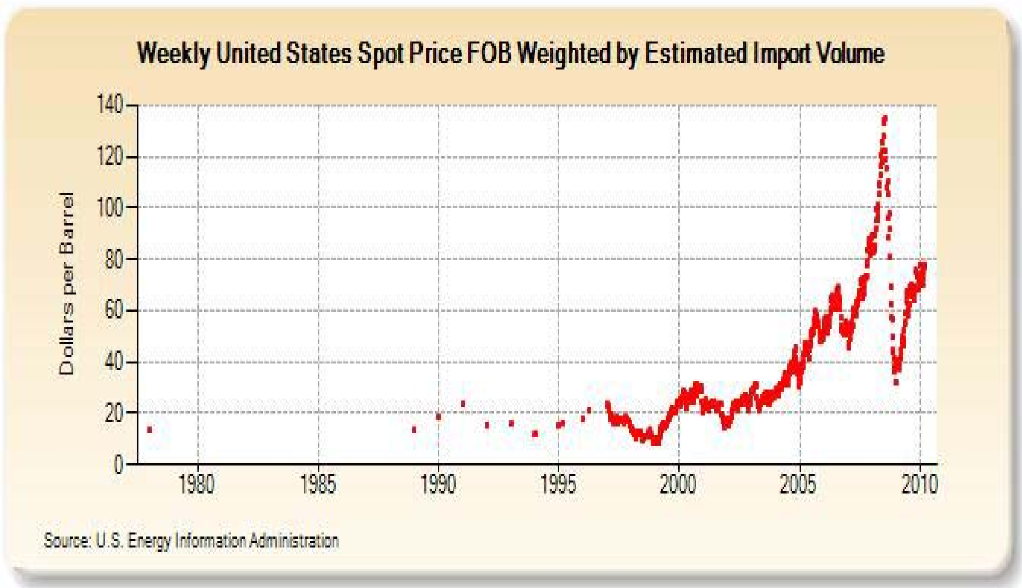


Figure 1.1 Graph of Petroleum Prices per Barrel from 1978 to 2010 [2]

Looking at the statistical graph shown below in fig 1.1[2] we can conclude that cost of petroleum products are gone really sky high in recent history. As a result we need a cost effective energy source in our daily life for utilization. Optimum solution to this problem can be solar energy. Also, solar energy can be stored in the storage devices like solar cells or in the thermal fluids which can be consumed when needed.

1.2 Advantages of Solar Energy

Solar energy is advantageous to the mankind in various ways. Some of them are stated as follows:

- It is renewable source of energy
- Available in abundant amount
- Can be stored into the storage cells
- Very cost effective
- Environment friendly (no pollution)
- Available in any weather conditions

1.3 Selection of Site in California

In generation of solar thermal power only direct sunlight can be used, which is called ‘beam radiation’ or Direct Normal Irradiation (DNI). DNI refers to the fraction of solar radiations which are not deviated by clouds, fumes or dust in the atmosphere and that reaches the earth’s surface in parallel beams for concentration. Thus, it must be located at the sites with the direct and maximum sunlight exposure. [3]

In other terms the site must be having sufficient solar insolation level. NREL has developed insolation estimates for the U.S. based on solar measurements taken at a number of stations throughout the country, as well as computer modeling that uses meteorological data to predict insolation at a large number of sites.

According to NREL's measurements, the nation's most plentiful solar resources are found in the Southwest. California, Nevada, Arizona, New Mexico, Utah, Colorado and Texas, and they possess some of the best insolation values in the world.

According to DOE, "enough electric power for the entire country could be generated by covering about nine percent of Nevada – a plot of land 100 miles on a side – with parabolic trough systems." In all, the U.S. has a relatively abundant supply of solar resources. A 1 kW solar electric system in the U.S. can generate an average of more than 1,600 kWh per year, while the same system in southern Germany (which installs eight times as many PV systems as the U.S.) would be able to generate only about 1,200 kWh per year, due to that nation's weaker insolation. A 1 kW system installed in parts of Nevada, Arizona, New Mexico and far West Texas can produce 2,100 kWh per year. [4]

Now, here is the Solar Insolation Level Chart for USA. In which, we can figure it out that in CA (California) a place called Inyokern has highest Solar Insolation level which is

8.7 KWh/m^2/day**,** which is Highest

6.87 KWh/m^2/day, which is Lowest

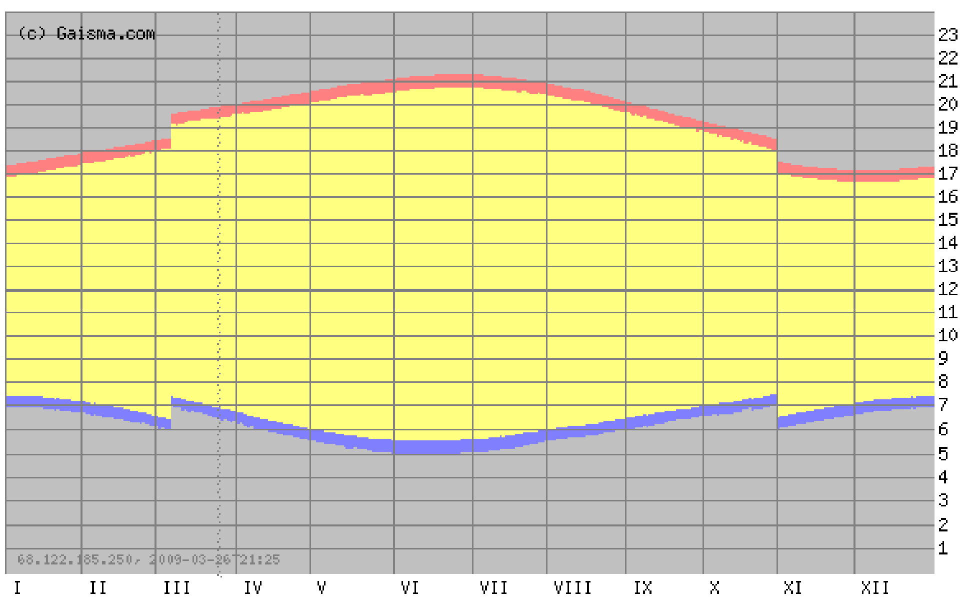
7.66 KWh/m^2/day, which is Average

Inyokern, CA is 380 Miles away from Sacramento, CA towards south side.

State	City	Solar Insolation Level			
		High	Low	Avg.	
		(KWh/m2/day)			
California	Santa Maria	6.52	5.42	5.94	
California	Riverside	6.35	5.35	5.87	
California	Davis	6.09	3.31	5.1	
California	Fresno	6.19	3.42	5.38	
California	Los Angeles	6.14	5.03	5.62	
California	Soda Springs	6.47	4.4	5.6	
California	La Jolla	5.24	4.29	4.77	
California	Inyokern	8.7	6.87	7.66	

Table 1.1 Solar Insolation Levels of California's Different Places [19]

Now, let us discuss about the Redding's climate condition and what the insolation level is of Redding from dawn to dusk i.e. 12 hours a day.



Darkness **Dawn** **Sunshine** **Dusk**

Figure 1.2 Redding's Climate from Dawn to Dusk [18]

Variable	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Insolation, kWh/m²/day	1.86	2.79	3.93	5.19	6.39	7.33	7.42	6.55	5.11	3.45	2.05	1.64

Table 1.2 Redding's Insolation Level Hour-by-Hour [18]

Therefore, Average insolation level in Redding, CA, USA is 7.33 KWh/m²/day in normal environment. As we have enough level of insolation, favorable weather and farmlands within the region, we have decided to install a solar power plant in Redding, CA.

Period	**Temperature**			**Rain**
	Min(F)	**Avg (F)**	**Max(F)**	**Avg (inch.)**
January	37.4	46.2	54.9	8.0
July	68.1	83.3	98.4	0.2
Average Annual Precipitation - 39.4 inches				
Average Annual Snowfall - 4.8 inches				

Table 1.3 Redding's Climate Condition [18]

Availability of clean water in Redding, CA:

Clean (ground/surface) Water: 30,000 ac-ft. /year to 80,000 ac-ft. /year

Location: Redding Basin, Shasta County [19]

Chapter 2

SOLAR THERMAL POWER PLANT

As California is blessed with abundant sunlight exposure, we should make use of that energy available very efficiently. Recently US government has taken a step forward in this direction and making negotiations with Australia based (also located at Mountain View, California) solar-steam generator company Ausra to build the solar thermal power plant in California to generate the electricity for nearby locations.

2.1 Solar Thermal Power Plant Overview

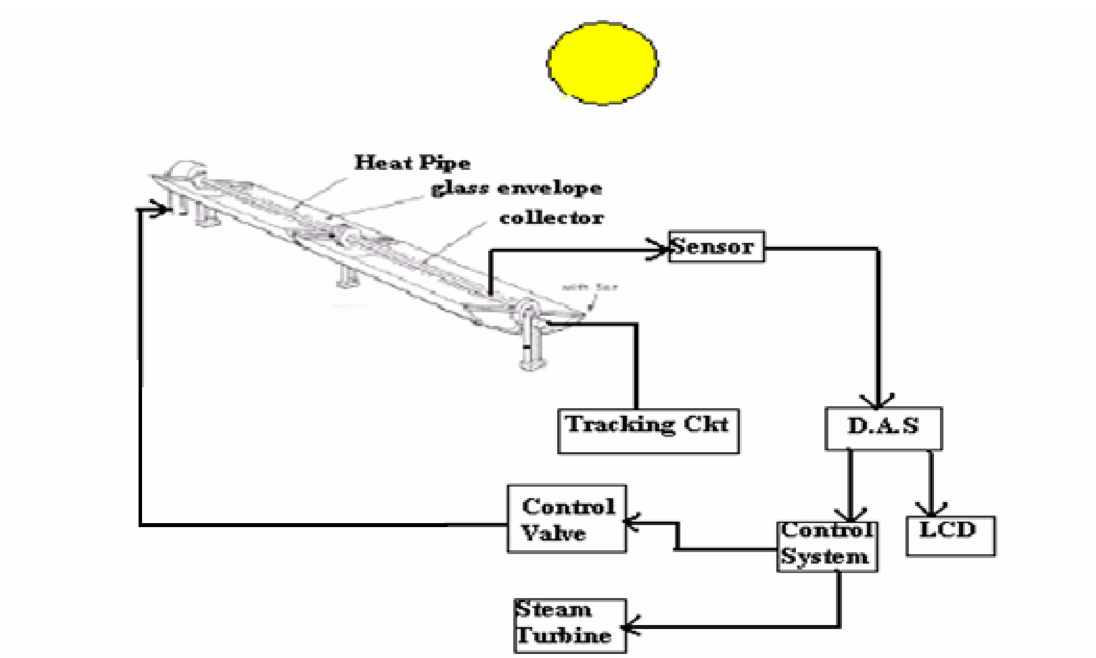


Figure 2.1 Block Diagram of Solar Thermal Power Plant

The principles of conversion of solar energy into electrical energy in solar thermal power plant have been known for more than a century. However, its commercial scale-up and exploitation has only taken place since the mid 1980s.

Generating electrical energy from the energy obtained from solar radiation is very simple and straight forward process. Direct sunlight can be concentrated and gathered by a range of Concentrating Solar Power (CSP) technologies to provide medium to high temperature heat. This heat is then used to operate a conventional power cycle, for example through a steam turbine. Solar heat collected during the day can also be stored in liquid or solid media such as molten salts, ceramics, etc. In this project we will be storing the solar heat in the liquid like water or glycol. At night, it can be extracted from the storage medium thereby continuing turbine operation. [3][1]

Looking at the block diagram of the solar thermal power plant we can see that it consists of following sections:

- Tracking Circuit
- Pressure Sensor
- Data Acquisition System
- Display (LCD)
- Control System

- Control Valve

The focus of this report is mainly on the pressure sensor for pressure measurement and control of generated steam and the sun tracking system. Measurement and controlling of pressure in the steam generator and the sun tracking will be discussed in detail in following chapters.

2.2 Use of Fresnel Reflectors

For sun tracking either parabolic dishes or Fresnel mirrors can be used. In this project design Fresnel reflectors will be used designed by a company Ausra. Ausra uses Compact Linear Fresnel Reflector (CLFR) solar collector. It is a specific type of Linear Fresnel Reflector (LFR) technology that uses long, thin mirror segments to focus sunlight onto a fixed absorber located at a common focal point of the reflectors.[4][1] Fresnel mirrors are capable of concentrating the sun’s energy to 30 times (approximately) its normal intensity. The absorber is containing the thermal fluid which gathers and stores the energy obtained by the concentrated sunrays on the former by Fresnel reflectors. The concentrated sunlight boils the liquid in the heat pipes, generating high pressure steam. This high pressure steam is used directly in the power generation eliminating the need for the costly heat exchangers. This superheated steam is then retained in the steam generator, allowing for a more seamless integration with the electric grid.[4]

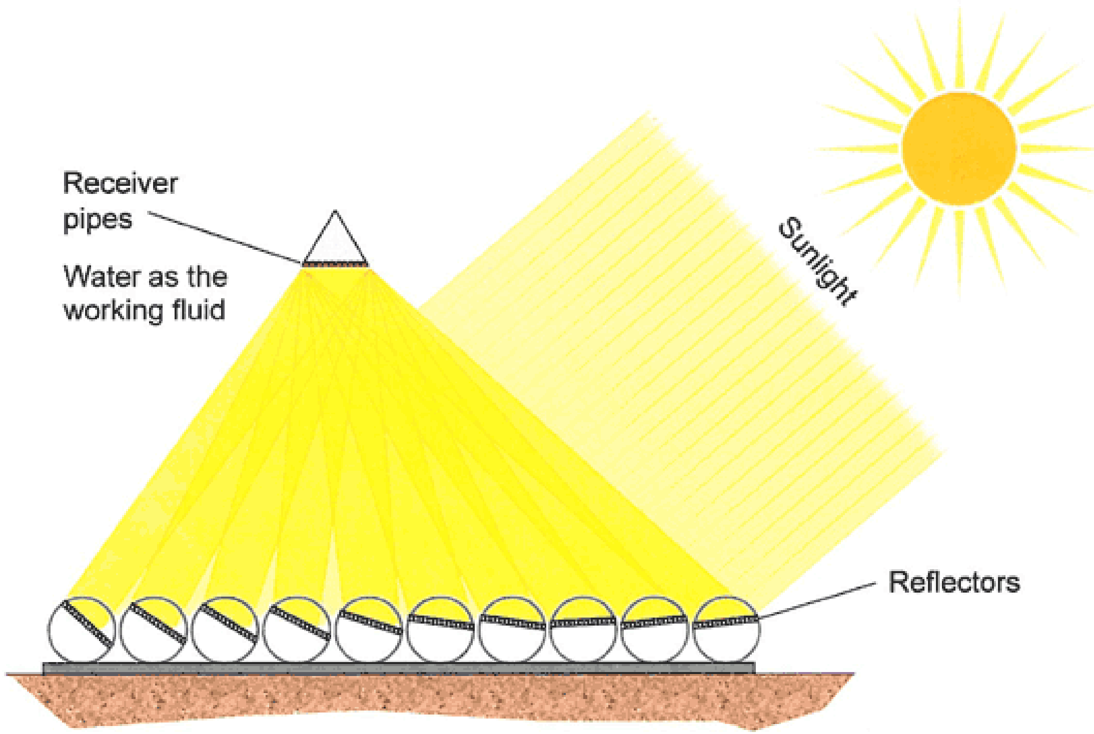


Figure 2.2 Fresnel Reflectors Concentrating Sunlight on Absorber [1]

As seen in the figure 2.2 Fresnel reflectors are located at the base of the system and converges the solar radiation into the absorber. The reflectors are typically aligned in a north-south orientation and turn about a single axis using computer controlled solar tracking system. This allows the system to maintain perpendicular incidence between the sunrays and the Fresnel mirrors, thus optimizing the energy transfer. [4]

Receiver pipes in the above figure are absorbers containing the thermal liquid which are located at the focal point of the Fresnel reflectors. The former runs parallel and above of the later to transfer heat obtained from the solar radiations to the thermal liquid.

2.3 Absorbers Used in Compact Linear Fresnel Reflector System

In CLFR systems, the basic design of the absorber is an inverted cavity with the glass coating enclosing the insulated heat pipes. Above presented figure demonstrates the basic design of the absorbers used in CLFR.

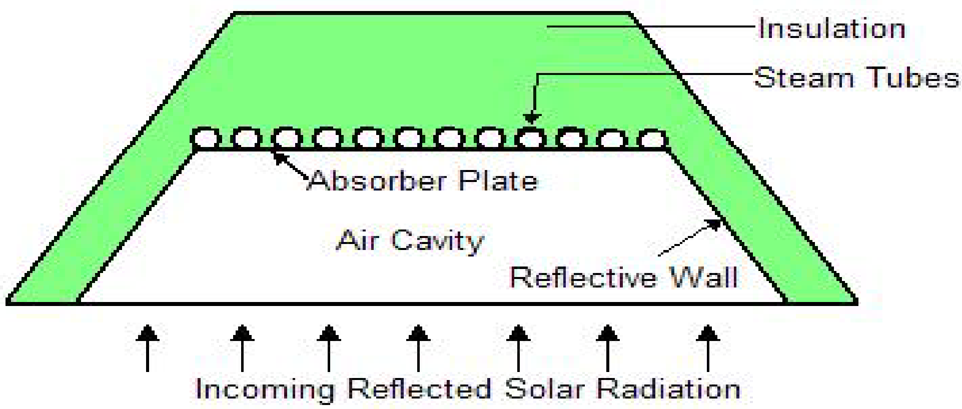


Figure 2.3 Absorber Used in Compact Linear Fresnel Reflector System[5]

To optimize the performance of the CLFR system, each component should be designed with highest degree of optimization. Design of the absorbers also plays a very significant role in optimizing the system's performance. Absorbers must be designed such that the heat transfer between the absorber and the liquid is maximized.

This relies much on the surface of the heat pipes. So, electro-chemically deposited black chrome is generally used to optimize the performance and also to give ability to withstand the surfaces against high temperatures. [5]

Uneven distribution of the temperature along the surface hikes the rate of degradation of the surface. Thus, utmost care should be taken about the heat distribution across the surface of the absorbers used in the system. This can be achieved by changing the parameters such as the thickness of the insulation above the place, aperture size of absorber and the shape and depth of the cavity.

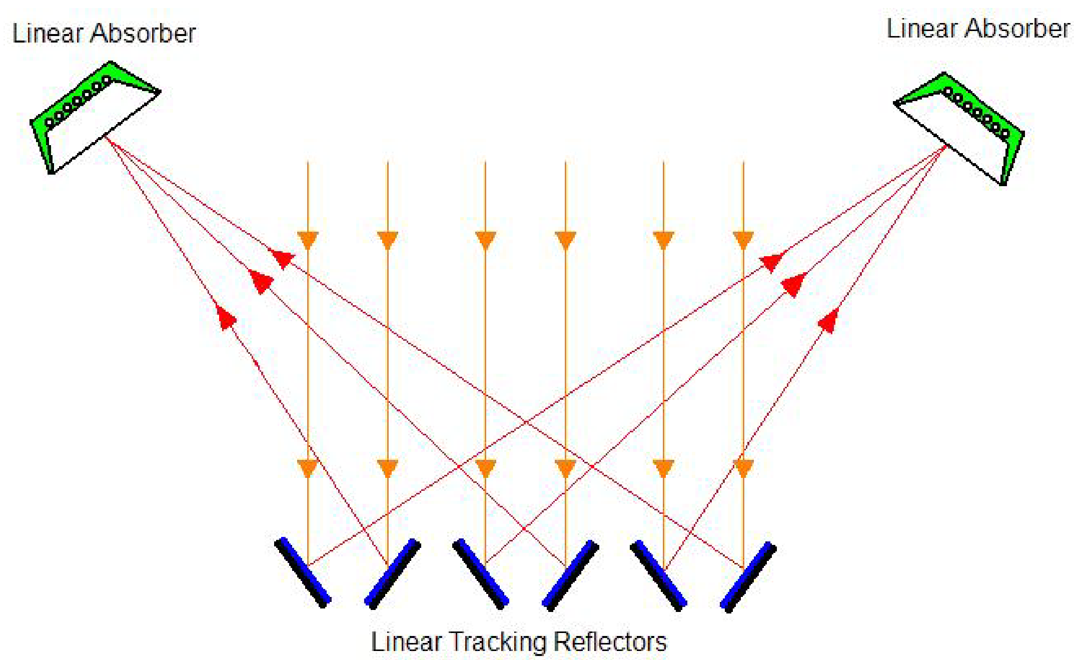


Figure 2.4 CLFR Alternating Inclination [5]

Unlike traditional Linear Fresnel reflectors, CLFR uses multiple absorbers within the vicinity of its mirrors. This arrangement is advantageous in many ways. First, additional absorbers allow the mirrors to alternate their inclination angles as per seen in figure 2.4. This in turn minimizes the shadowing issue of the adjacent reflector, thereby optimizing the system efficiency. Secondly, addition of multiple absorbers reduces the amount of space required for installation and thereby reduces the overall cost of installing system. Also, as the panes are in the close proximity, it results into reduction in the length of the absorbers and thereby minimizing the thermal loss. [5]

2.4 Brief Description of Other Building Blocks of Solar Thermal Power Plant

Other building blocks of the solar thermal power plant are data acquisition system, pressure measurement and control in the heat pipes and steam generators, tracking circuit, turbine etc. Data acquisition system (DAS) keeps track of the solar insolation level obtained at predetermined interval of time. It gathers data of temperature, pressure and insolation levels and stores into the storage devices for future references. DAS in our project is designed by other project partner. Other inseparable part of this project is sun tracking circuit uses the solar insolation level data obtained from the DAS and aligns the reflectors into proper direction to get maximum solar radiation. Pressure measurement and control system provides data of pressure inside the heat pipes and the steam generator and also controls the same to avoid any possible accident.

Chapter 3

SUN TRACKING

3.1 Concept of Solar Power

Solar power plant is same as other conventional power plant; the only difference is that it uses sunrays as a source of energy, which is inevitable, and most efficient and economical source of energy.

Energy from sun comes to earth in forms of sunrays. In solar power plant we are using this energy for the solar power plant. Fresnel Mirrors is the heart of this whole power plant. By using Fresnel Mirrors, we can concentrate all the sunrays falling on to it to one particular point. Concentrating solar collectors use shaped mirrors or lens to provide higher temperatures those flat plate collectors. By concentrating all these rays, we can get extremely high temperature at this point with the help of this high temperature we can convert liquid into vapor form. [14]

Fresnel diffraction mirror is a kind of atomic mirror, designed for the seculars reflection of neutral particles coming at the grazing incidence angle, characterized (Shown) in the following figure 3.1.

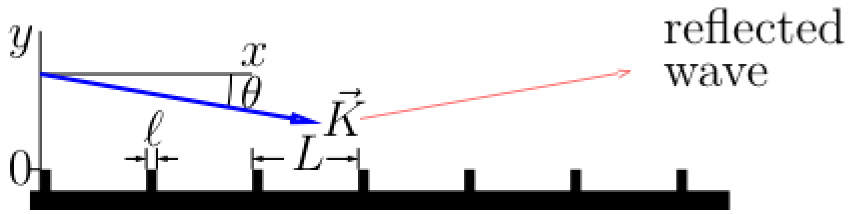


Figure 3.1 Incidence Angle of Fresnel Mirror [14]

Here in our case we are using water as a liquid and due to high temperature, this water gets converted into a steam.

Figure 3.2 Fresnel Mirror Plates [14]

With the help of this steam and closed-loop circulation principle, energy conversion from one form to another can be possible. The pressure of this resulting steam measured by the means of pressure sensor and this value is stored in a temporary register and displayed on the LCD.

Steam pressure should not be increased or decreased from pre-defied value if it does then it should automatically compensate which can by monitoring the developed logic which we have used in a microcontroller based circuit for the regulation of the desired pressure as required to be operated in the plant.

Tracking circuit is needed for automatic positioning of sunrays to a dish. This circuit constantly tracks the sun in accordance to get maximum sunrays falling perpendicular on the aperture surface of the dish. With the help of this Fresnel Mirror (lens) all rays are concentrated to one particular point, following the sun by turning around its length-axis is sufficient to provide a line focus.

A black absorber tube is located in this focus line, surrounded by a glass envelope. The space in between is evacuated to prevent heat losses by convection or conduction. A heat transfer medium inside the absorber tube receives the heat and transports it to the Collector tube from where it is fed to the power block. Due to high concentration, we can get very much high temperature there. Now we have kept one glass enveloped tube at this point and liquid is passing through it, now due to high temperature this water gets converted into steam, we gave used glass tube with surface colored black so that it prevents heat loss. We are using here feedback system so that we can increase efficiency. A Fresnel lens is a type of lens invented by French Physicist Augustin-Jean Fresnel Originally developed for lighthouses. The design enables the construction of lenses of large aperture and short focal length without the weight and volume of material, which would be required in conventional lens design. Compared to earlier lenses, the Fresnel lens is much thinner, thus passing more light and allowing lighthouse to be visible over much longer distances. [14]

3.2 Parabolic Errors

There are some errors related to parabolic mirror (dish). Therefore, we are not using parabolic mirror in this project. Instead of that, we are using Fresnel mirrors and for that, we will use Sopogy Inc. using SopoNova4.0 and MicroCSP technologies. In the next section, we will discuss about Sopogy Inc. and its technologies. However, in this section we are discussing errors related to parabolic mirror (dish). [15]

Following figure 3.3 is an illustration of the different types of potential errors that may be encountered in parabolic Collectors

(1) Materials:

- Specularity of the reflective material

(2) Fabrication:

- Local slope errors: waviness of the reflector surface
- Profile errors: The average shape of the reflector (obtained by averaging the local slope errors) may differ from a part
- Misalignment of the reflector
- Dislocation of the receiver tube

(3) Operation:

- Tracking errors: initial poor quality or degradation of equipment
- Profile errors due to wind loading and/or weathering
- Degradation of reflector surface due to dust, dirt and general weathering
- Misalignment of the receiver due to sagging or buckling and other thermal or thermal cycling effects [16]

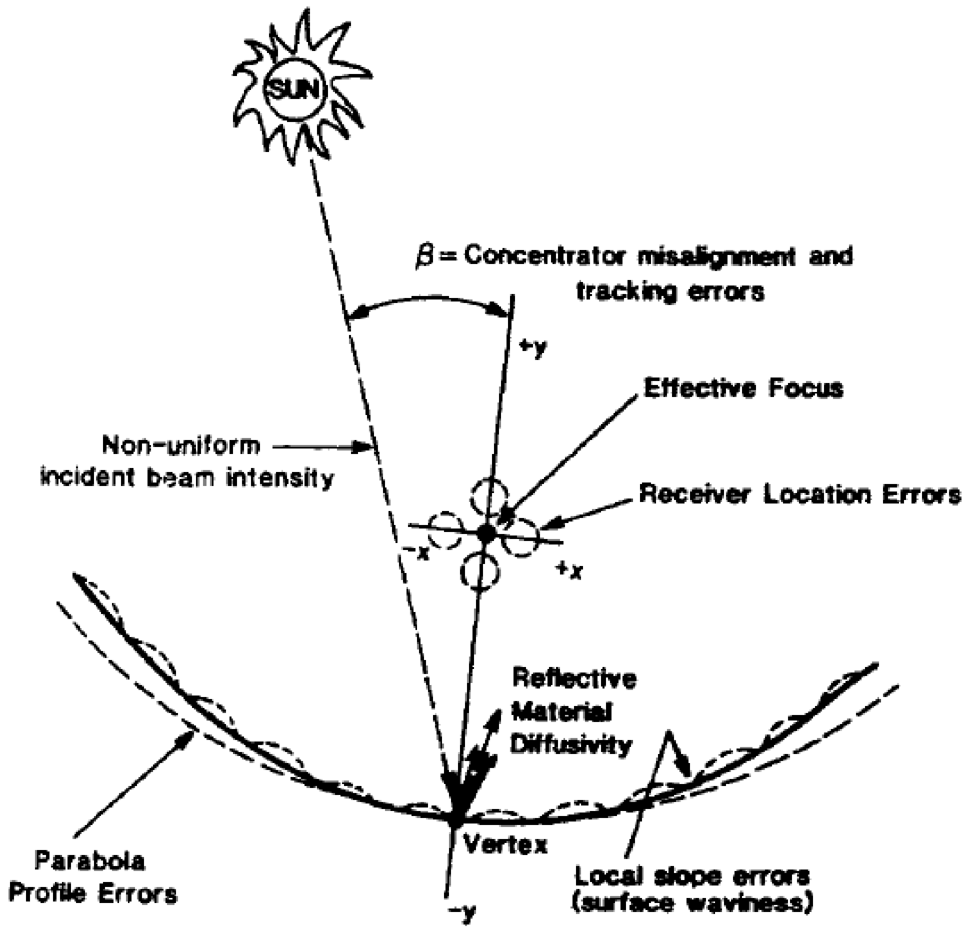


Figure 3.3 Descriptions of Potential Optical Errors in Parabolic Collectors [16]

In the analysis of statistical or random errors, errors are assumed independent stochastic processes, and their occurrences are represented by normal (probability) distributions. The distribution of energy directed toward the receiver is then obtained by convolution (Following Fig). The random errors include Following:

- Apparent change in the sun's width due to atmospheric effects

- Scattering at the reflector due to its optical properties or random slope errors
- Random misalignment.

Non-random errors are deterministic, and the can have a greater impact on the operation of the collector. They account for the gross errors in the manufacture/assembly and/or operation on the collector. This can be the result of either misdirecting the central ray from the reflector surface or misplacing the receiver or both. [16]

The non-random errors are identified as follows:

- Reflector profile errors due, for example, to deflection or severe waviness of the reflector surface causing a permanent change in the location of the (ideal) focus of the reflector,
- Consistent misalignment of the collector with the sun due, for example, to a constant tracking error or rotation of the collector’s vertex-to-receiver axis during assembly, and 3) misalignment of the receiver with the effective focus of the collector. [16]

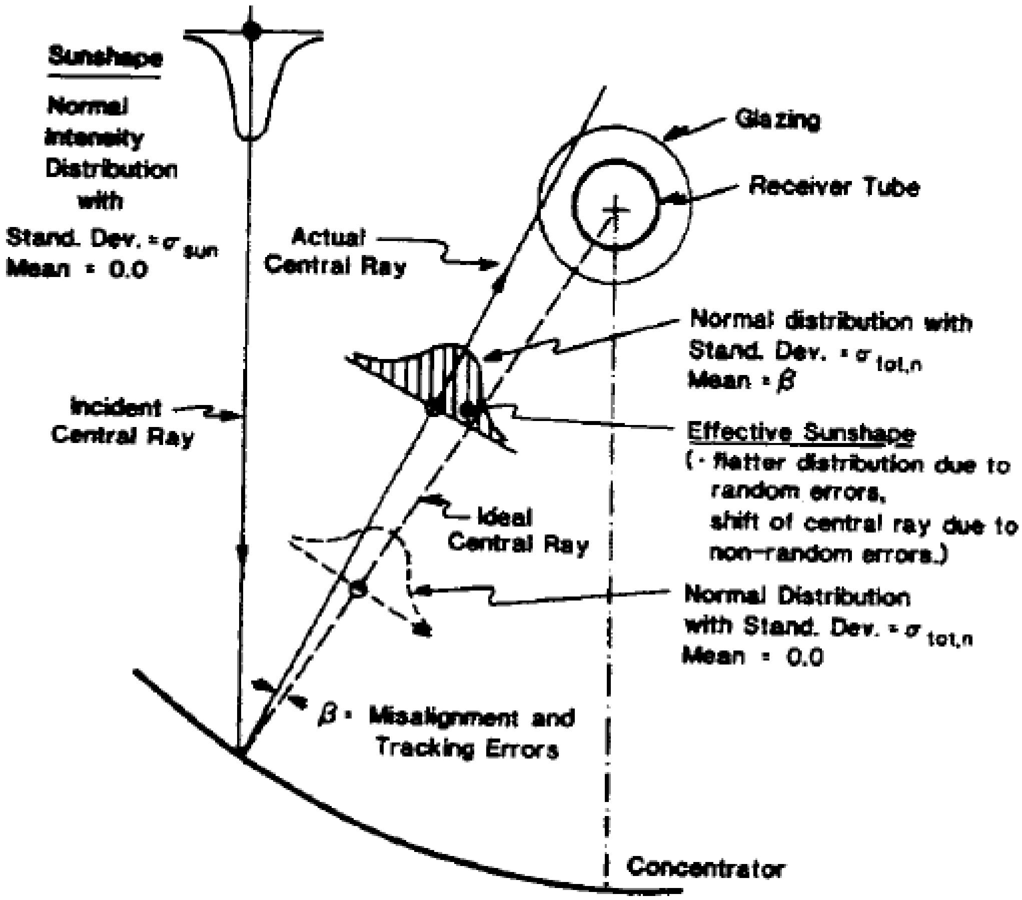


Figure 3.4 Modeling of Potential Optical Errors in Parabolic Collectors [16]

3.3 Algorithm for Tracking

As we discussed earlier, tracking of sun is most important aspect of the solar power plant. Thus need is arise to choose the best possible technique to track down the solar trajectory. To make this happen we have the Maximum Power Point Technique (MPPT) in the picture to give us a clear idea.

A maximum power point technique is a highly efficient DC to DC converter. It functions as an optimal electrical load. MPPT then converts the power to a voltage or current level which is the most suitable to the designed load system. The system tracks the peak value of voltage and current of the solar storage and gives the maximum output. [10]

Algorithm that is used to code software part of this system is pertube and observe algorithm which is also called P & O algorithm in short. On industrial basis to track down the sun trajectory and get maximum output, P&O is the most efficient and relatively very simple algorithm.

3.4 Flow Chart of P & O Algorithm

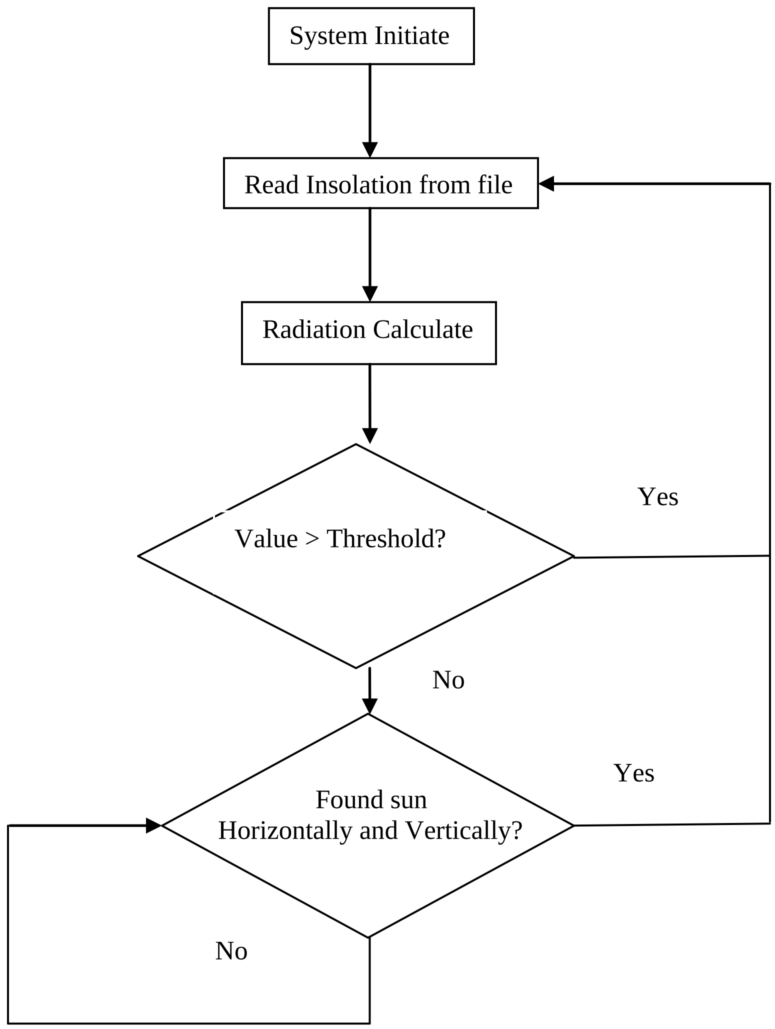


Figure 3.5 Flow Chart of P & O Algorithm

3.5 Simulation Results for Given Insolation:

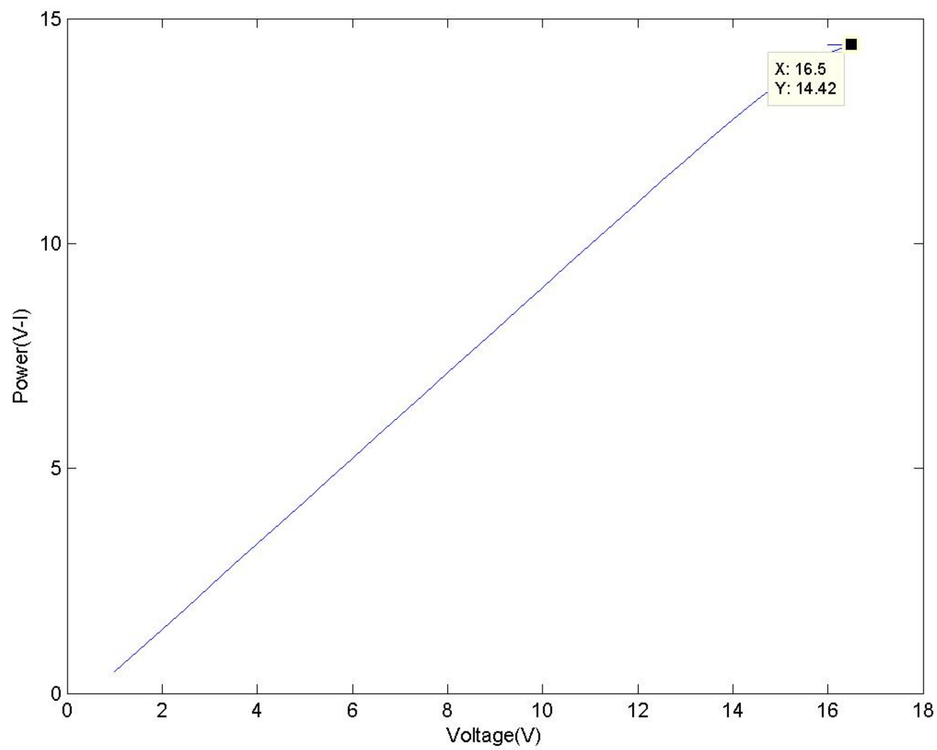


Figure 3.6 Plot of Voltage Vs Power for Insolation = 250W/m² and Temp = 25ºC

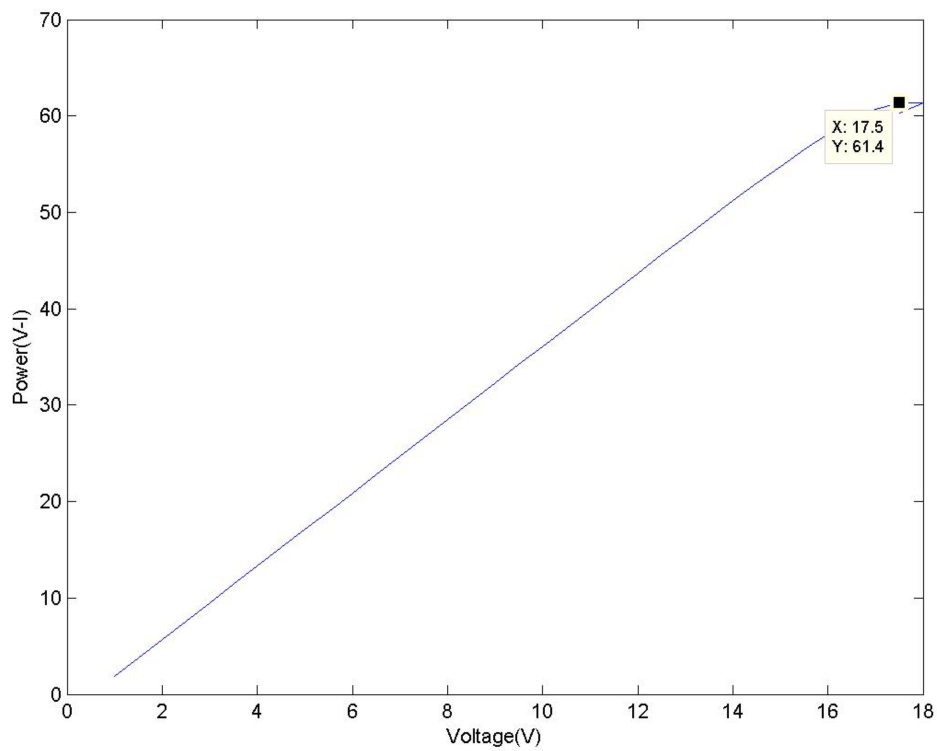


Figure 3.7 Plot of Voltage Vs Power for Insolation = 1000W/m² and Temp = 25ºC

3.6 Codes

Generating I-V characteristic for different values of Insoaltions and Temperature

```
function I= mysun(V,G,Tcell)

V= solar module voltage;
 I= module current
G= Solar insolation (1G=1000W/m2);
Tcell=Cell temperature;


% first define all the constant

A=1.2;           diode ideality factor
Vbg=1.12;          band-gap voltage
Sc=36;           number of series cell
k=1.38e-23;     Boltzmann's constant
q=1.60e-19;     electron charge

temperature1=298;                 % temp. in Kelvin
Is_temperature1=3.80;
Vo_temperature1=21.06/Sc;

temperature2=348;                 % temp. in Kelvin
Is_temperature2=3.92;
Vo_temperature2=17.05/Sc;

Tr=273+25;                  % reference temp
Tw=273+Tc;                  working temperature

%Calculate light generated current

Il_temperature1=Is_temperature1*G;

p= (Is_temperature2-Is_temperature1)/Is_temperature1;

e= 1/(temperature1-temperature2);

d= p*e;

Il=Il_temperaure1*(1+c*(Tw-temperature1));
```

```
  Vt_temperaure1=k*temperature1/q;

end
```

Maximum Power Point Technique Matlab code

```
function [out]= MPPT(V);

I=mysun(V,.G,Tcell);
Pwr=V*I;

% Define  constant

p=0.5;

tp1=zeros(1,40);

tp2=zeros(1,40);

Vr_new=V+x;

for i=1:40

I_new=mysun(Vr_new,G,Tcell)

Pwr_new=I_new* Vr_new

 if (Pwr_new<Pwr)

          if (Vr_new>V)

               V_new=Vr_new-p;
          else
                V_new=Vr_new+p;
          end
 else
        if (Vr_new>V)

               V_new=Vr_new+p;
          else
                V_new=Vr_new-p;
```

```
        end
    end


 Vr_new=V_new

 Pwr=Pwr_new

 tp1(i)=V_new
 tp2(i)=Pwr_new

end

% plotting the graph of voltage versus power

 plot(tp1,tp2)

 xlabel ('Voltage')
 ylabel ('Power')

 Vm=V;
 Ip=I_new;
```

3.7 Results

Current values that are derived from our code for different values of Insoaltion

Insolation (G) = 250 W/m²		Insolation (G) = 1000 W/m²	
i/p → Voltage (V)	o/p→ Current (Amp)	i/p → Voltage (V)	o/p→ Current (Amp)
0	0.9500	0	3.8000
1	0.9500	1	3.8000
2	0.9500	2	3.8000
3	0.9500	3	3.8000
4	0.9500	4	3.8000
5	0.9500	5	3.8000
6	0.9500	6	3.8000
7	0.9500	7	3.8000
8	0.9500	8	3.8000
9	0.9499	9	3.7999
10	0.9498	10	3.7996
11	0.9495	11	3.7991
12	0.9487	12	3.7979
13	0.9467	13	3.7947
14	0.9418	14	3.7871
15	0.9300	15	3.7683
16	0.9010	16	3.7223
17	0.8311	17	3.6116
18	0.6674	18	3.3523
19	0.3089	19	2.7842
19.5	0.0022	20	1.7028
		21	0.1043

Table 3.1 Current Values Defined for Different Value of Insolation

Chapter 4

PRESSURE MEASUREMENT AND CONTROL

4.1 Pressure Measurement in Heat Pipes

Pressure measurement in heat pipes is critical so as to avoid high velocities of the vapor of working fluid. High velocities lead to high temperature difference between the ends of the heat pipes and causes flow instabilities. Hence, pressure control should be done precisely for minimizing losses in heat pipes. [6]

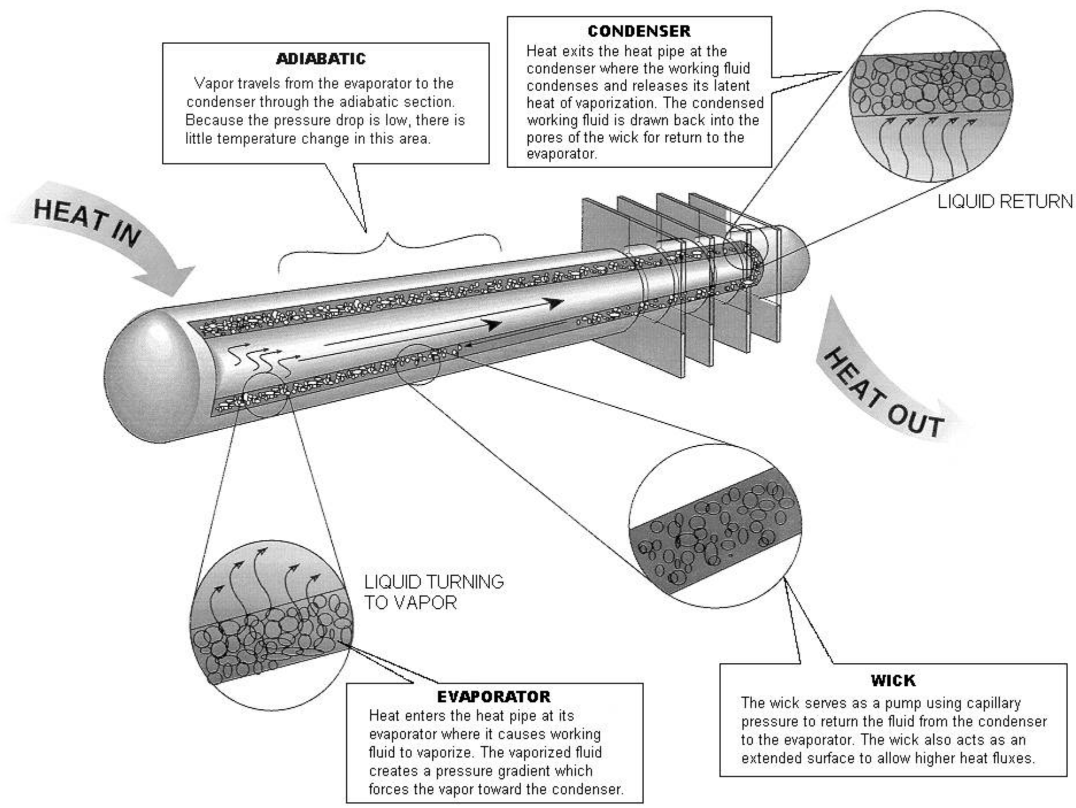


Figure 4.1 Pressure Measurements in Heat Pipes [6]

High temperature differential pressure measurement in heat pipes is done by using high precision pressure gauge. When selecting a pressure gauge consideration should be given to a number of parameters which have an effect on gauge accuracy, safety, and utility like:

- Accuracy required
- Dial size
- Operating pressure range
- Chemical compatibility with gauge construction materials
- Operating temperature range
- Humidity
- Vibration, pulsation, and shock
- Pressure fluid composition
- Method of mounting [7]

Following figure shows the rate control response and pressure vs. voltage characteristics of a typical pressure gauge used in heat pipes.

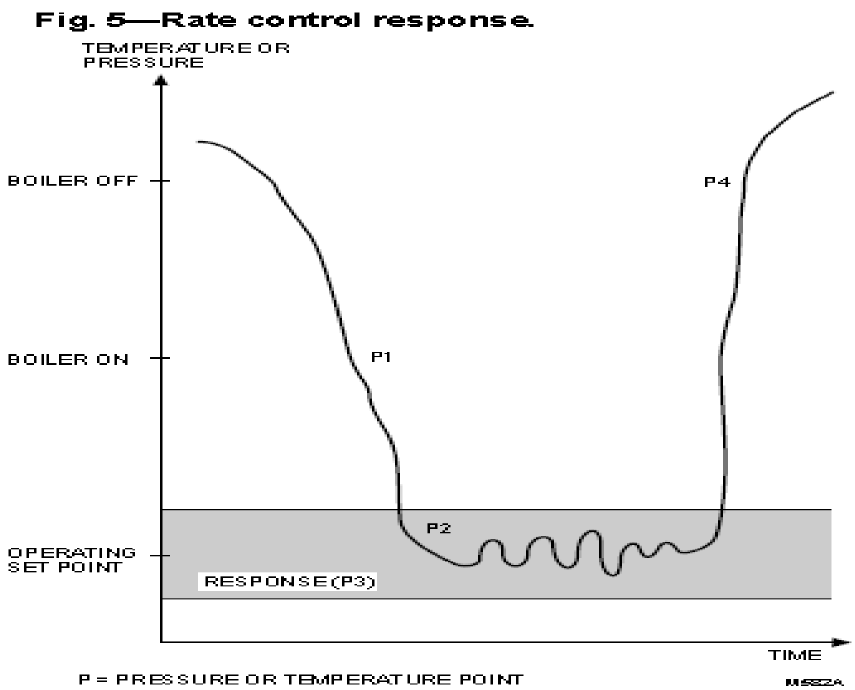


Figure 4.2 Rate Control Response [7]

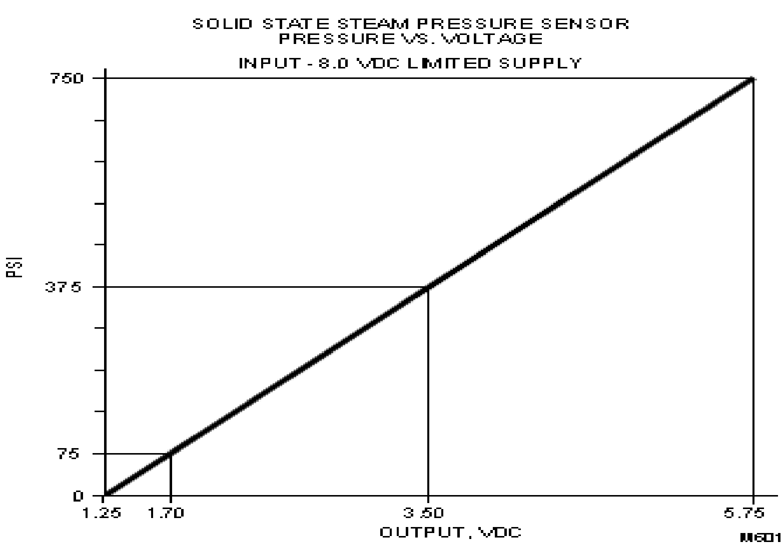


Figure 4.3 Pressure versus Voltage [7]

4.2 Construction of Pressure Gauge

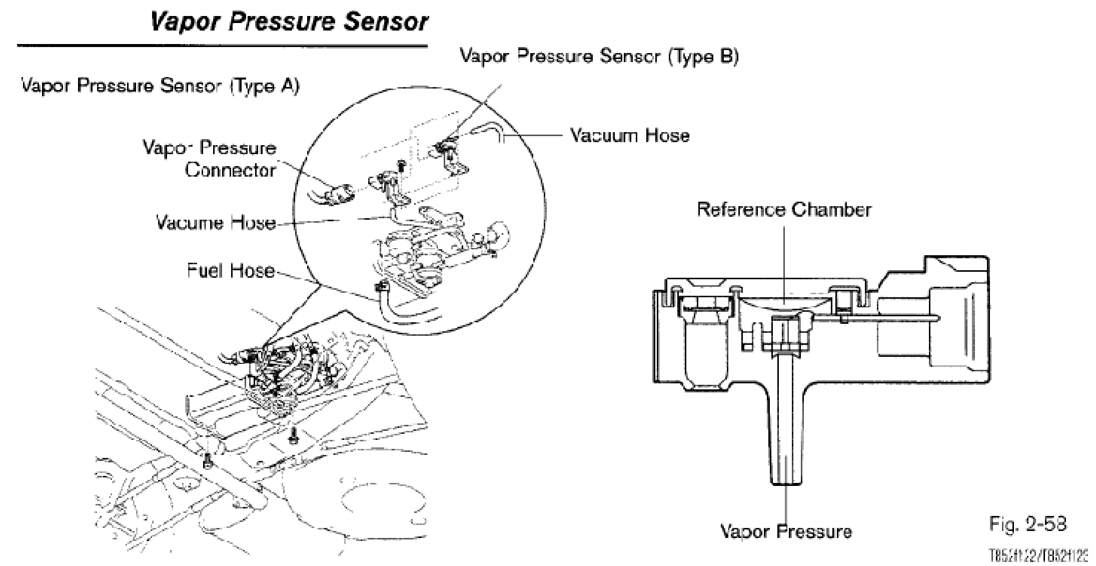


Figure 4.4 Vapor Pressure Sensor [9]

The Vapor Pressure Sensor (VPS) measures the vapor pressure in the evaporative emission control system. The Vapor Pressure Sensor may be located on the fuel tank, near the charcoal canister assembly, or in a remote location.[8,9].

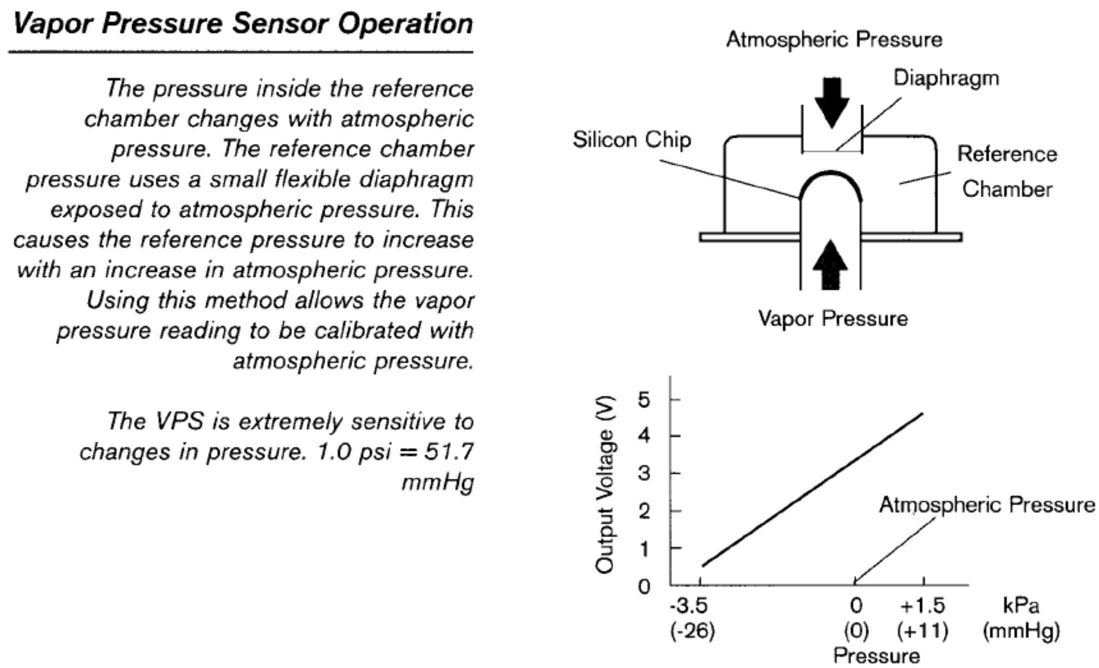


Figure 4.5 Vapor Pressure Sensor Operation [9]

This sensor uses a silicon chip with a calibrated reference pressure on one side of the chip, the other side of the chip is exposed to vapor pressure. Changes in vapor pressure cause the chip to flex and vary the voltage signal to the ECM. The output voltage signal depends on the difference between atmospheric pressure and vapor pressure. As vapor pressure increases the voltage signal increases. The sensor is sensitive to very small pressure changes(1.0 psi = 51.7 mmHg) [9].

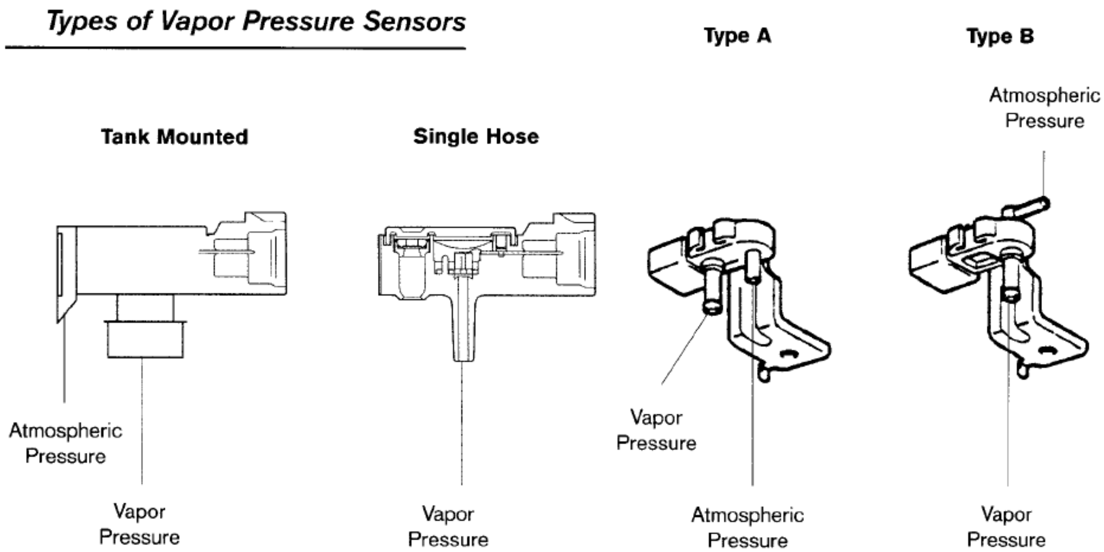


Figure 4.6 Types of Vapor Pressure Sensor [10]

Vapor pressure sensors come in variety of configurations. When the VPS is mounted directly on the fuel pump assembly, no hoses are required. For remote locations, there may be one or two hoses connected to the VPS. If the VPS uses one hose, the hose is connected to vapor pressure. In the two hose configuration, one hose is connected to vapor pressure, the other to atmospheric pressure. It is important that these hoses are connected to the proper port. If they are reversed, DTCs will set [10].

4.3 Pressure Control

Pressure control is crucial and critical for the success of solar thermal power plant. Pressure measurement is done at all points in the system. Pressurizer is used to control the pressure. If a pressure exceeds the pre set value, steam comes out from pressurizer via steam bleed valves. This causes the level in the pressurizer to rise and bring back the pressure back to pre-set value. Thus inventory control is correlated with the pressure control. Steady steam flow to the turbines leads to a constant power generation. If this generated power is removed from the system regularly, boiler pressure stays same. But if there is increase in the demand for power, valves must open up leading to higher intake of steam for the turbine. This leads to a decrease in the boiler pressure. If the pressure is lower than the pre-define value, it causes the heaters located in the pressurizer to turn on. This increases the pressurizer pressure thereby opening the feed valves. Opening of feed valves leads to higher flow of liquid and feed through it. This increase in flow of both feed and liquid from the feed valves increases both, pressure and temperature. [11].

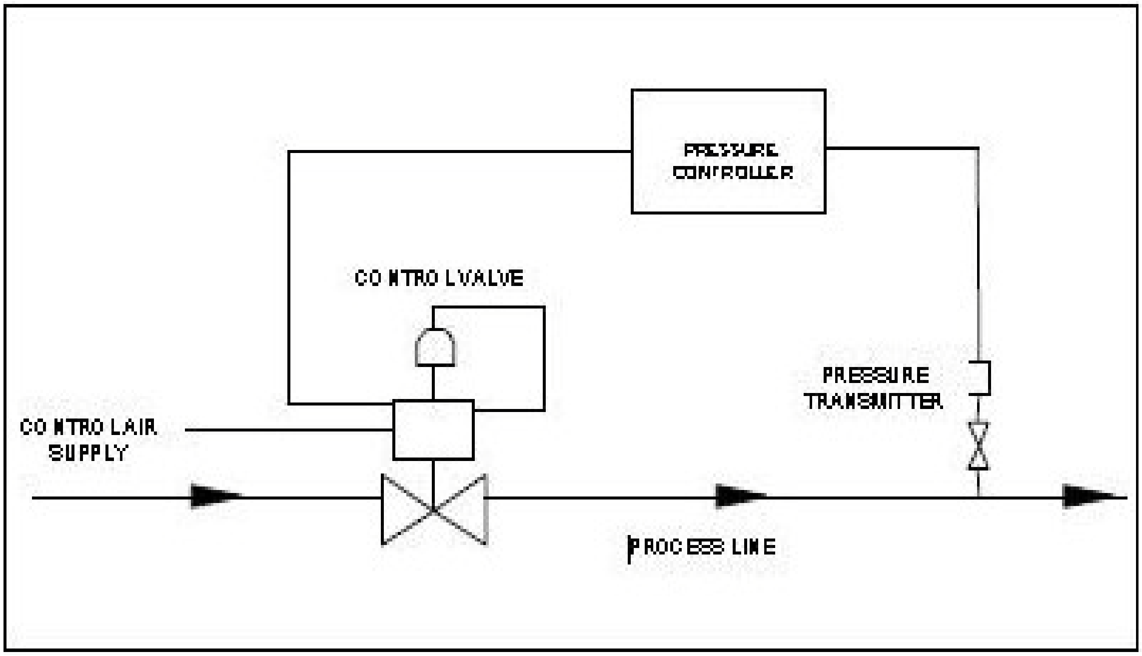


Figure 4.7 Typical Pressure Control Loop [13]

Reliable steam pressure regulators are critical to maintaining balance and smooth functioning in all types of boiler systems. Other valves which can used to be control the pressure in the system are:

- Pressure Reducing Regulators
- Pressure Loaded Control Valves
- Pressure Reducing Differential Control Regulators
- Relief Valve/Backpressure Differential Control Regulators
- Relief Valves/Backpressure Regulators [12]

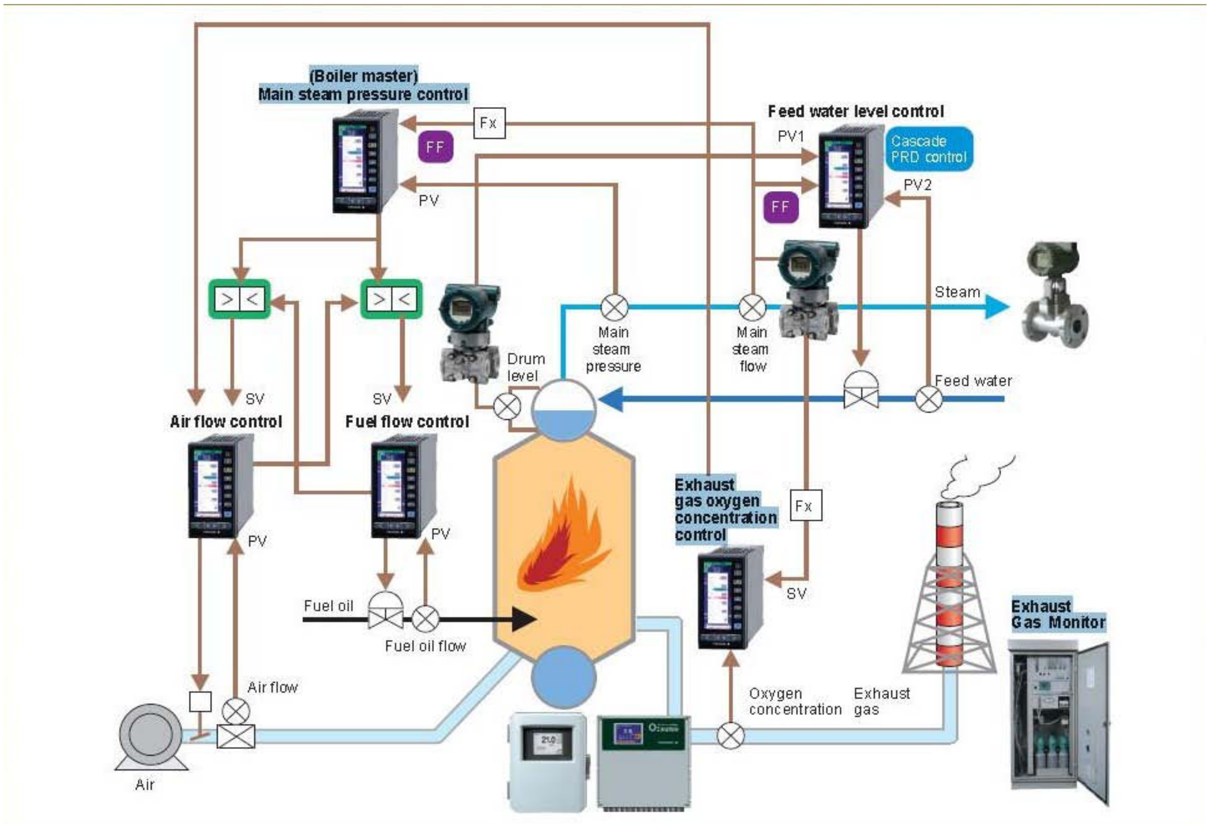


Figure 4.8 Pressure Control System [12]

REFERENCES

[1] http://www.ausra.com/ Date: 6/23/2009

[2] Weekly United States Spot Price FOB Weighted by Estimated Import Volume

http://tonto.eia.doe.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=wtotusa&f=w

Date: 4/3/2010

[3] Concentrated Solar Thermal Power

http://www.greenpeace.org/raw/content/international/press/reports/Concentrated-Solar-Thermal-Power.pdf Date: 6/23/2009

[4] Solar Thermal Energy

http://en.wikipedia.org/wiki/Solar_thermal_energy Date: 12/26/2009

[5] Compact Linear Fresnel Reflector

http://en.wikipedia.org/wiki/CLFR Date: 12/26/2009

[6] Heat Pipes

http://www.cheresources.com/htpipes.shtml Date: 2/4/2010

[7] Thermacore, Inc. - Lancaster, PA:Heat Pipe Design

http://www.bmpcoe.org/bestpractices/internal/therm/grf_therm_01.html

Date: 2/7/2010

[8] P7710 Solid State Pressure Sensor Boiler Control System 7700

http://www.cgnacontrols.com/members/product_documentation/65a49acce8b086a5.pdf

Date: 2/8/2010

[9] Pressure Gauge Selection

http://www.mcdanielcontrols.com/gaugeselection.htm Date: 3/1/2010

[10] http://www.autoshop101.com/forms/h35.pdf Date: 3/3/2010

[11] http://www.nuceng.ca/ep716/chap6.pdf Date: 3/4/2010

[12] Steam Pressure Regulators Date: 3/15/2010

http://www.industrialboiler.com/boiler-room-equipment/steam-pressure- regulators.aspx

[13] UFC Boiler Control Systems Date: 3/13/2010

http://www.wbdg.org/ccb/DOD/UFC/ufc_3_430_11.pdf

[14] Fresnel Mirror Date: 1/3/2010

http://en.wikipedia.org/wiki/Fresnel_mirror

[15] Sopogy Date: 1/7/2010

http://en.wikipedia.org/wiki/Sopogy

[16] Authors: Richard B. Bannerot and Halit M Guven

Title: Universal Error Analysis for the optical design of parabolic through solar collectors

Source: IEEE

[17] Maximum Power Point Tracker Date: 10/6/2009

http://en.wikipedia.org/wiki/Maximum_power_point_tracker

[18] Redding, California – Sunrise, sunset, dawn and dusk times for the whole year http://www.gaisma.com/en/location/redding-california.html Date: 5/3/2009

[19] Water Quality

http://www.ci.redding.ca.us/water/quality.htm Date: 9/6/2009