MS-EE Thesis

Design & Implementation of CPV/T System in Combination with Thermo Couple Module for University of Management & Technology

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DECLARATION

I **Muhammad Yasir** certify that this is my own work and the work has not, in whole or part, been presented elsewhere for assessment

Signature

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“Dedicated to my Father (late), Mother, Teachers and all family members whose efforts and prayers made me able to stand at this position today”

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PV	**Photo Voltaic**
CPV	**Concentrated Photo Voltaic**
CPV/T	**Concentrated Photo Voltaic & Thermal System**
PWM	**Pulse Width Modulation**
MPPT	**Maximum Power Point Tracking**
OIC	**Optimal Incident Angle**

LIST OF ABBREVATION AND DEFINATION

SYMBOLS & DESCRIPTION

η c = Cell Efficiency

Tc= Cell Temperature

P_c= Electrical Power of a Single Cell

f = Non ideal Factor

η_{opt}= Optimal Efficiency

G_{ind} = Direct radiance

K_t = Temperature's correction coefficient

P_{par} = Module loss

G_{par} =Losses factor

ABSTRACT

The past decade has proved itself to be an era of innovations in the field of Renewable energy especially in the Solar Based Power Generation. Much work is done on it but there is always a room for betterment and innovation. This thesis proposes a technique of increasing the efficiency of solar based generation of electricity with help of solar concentrator along with the thermal constraint. This proposed system is actually a hybrid system in nature where you get output energy not only in form of Electrical Energy but as well as in the form of thermal energy. The thermal constraints act as a double usable variable, which is used for cooling as well as the medium for carrying thermal energy. Water has been used as a thermal energy carrying material. We simulated the run time data of Lahore City and simulated the system for all months of the year. Different variables where analyzed in order to find out the maximum efficiency of the system.

OBJECTIVE

The objective of this Research was to design and implement a Hybrid CPV/T system along with a minimal modification to increase its Electrical output.

The target area for this system was kept the University of Management & Technology, Lahore. All Data related to the location was used.

In order to enhance the Electrical Efficiency, we developed a new approach of using a Thermo Couple / Thermo Electric Module which was used at the output of Thermal Energy. The Thermo Couple increased the Electrical Output for folds.

CHAPTER # 1: INTRODUCTION

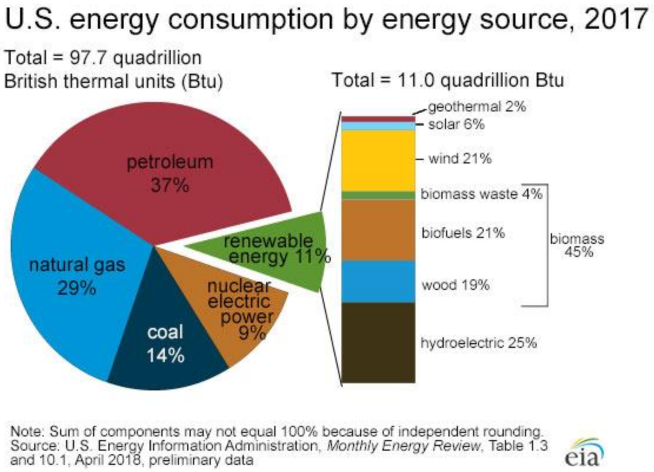
“Innovation is taking two things that already exists & putting them together in a new way”

-Tom Freston

1.1 Need For Renewable Energy?

Ever since the creation of mankind newer & newer discoveries & inventions are being made. These discoveries and inventions changed the human life all together. Out of all these inventions and discoveries the discovery of chemical fuels and the invention of the engines & ways to use them for the utilities of life. But as the time passes, the reserves of these natural resources are drastically decreasing [3]. Moreover such resources use lead to the production of many by products such as carbon monoxide etc [1].

Fossil Fuels till date are the most used energy resource around the world. Energy Investigation Department (EIA) of USA, Fig 1.1 indicates that by the end of 2017 the use of petroleum, natural gas & coal consumption combined made a dominating 80percent of Energy Resources that are being used [2].



U.S. energy consumption by energy source, 2017

Note: Sum of components may not equal 100% because of independent rounding.
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2018, preliminary data

Figure 1.1: Percentage contribution of Energy Resources in 2017 [4].

This factual problem lead to the development of renewable & clean energy source that is cheap, readily available and is doesn’t cause the production of any kind of byproducts [3]. Solar Energy production can be brought into use in many different ways: one way is to use it for the direct production of Electrical Energy & the other one is to produce energy is form of solar thermal energy. To produce energy in form of solar thermal energy, we use different kind of solar collectors that gather energy for the purpose of fluid heating or for air filled space heating or cooling. In contrary to this for the production of Electrical energy, Si wafers or other such semi-conductor materials are used that converts the solar energy directly into electrical energy. Therefore this process is called Photovoltaic system (PV), and when concentrated solar energy is used to produce electrical energy this process is named as Concentrated Photo-Voltaic (CPV) [3].

1.2 Concentrated Photovoltaic System

Among various different technologies available, the latest of them all is the concentrated photovoltaic (CPV). The key advantage of CPV is the high efficiency, as well as the less expensive semi-conducting PV material is required in order to achieve a high output from the system [5]. The principal advantage achieved by concentrating the radiations of sun through the process of magnification is that the solar radiation value is increased hundreds of time than it actually is, thus increasing the output generated through the solar panel [6]. This process aids in dealing with the problem of getting a high amount of power from a limited amount of panel.

1.2.1 Types of Concentrator

Concentrator increases the amount of photons and radiation that are hitting the solar plate. They do it by different means. On the basis of this it is divided into different types:

1. Parabolic Trough System
2. Power Tower
3. Solar Dish Generation

In all these types the ultimate goal is to concentrate the amount of radiation hitting a specific area to a specific point so that the efficiency of the system can be increased.

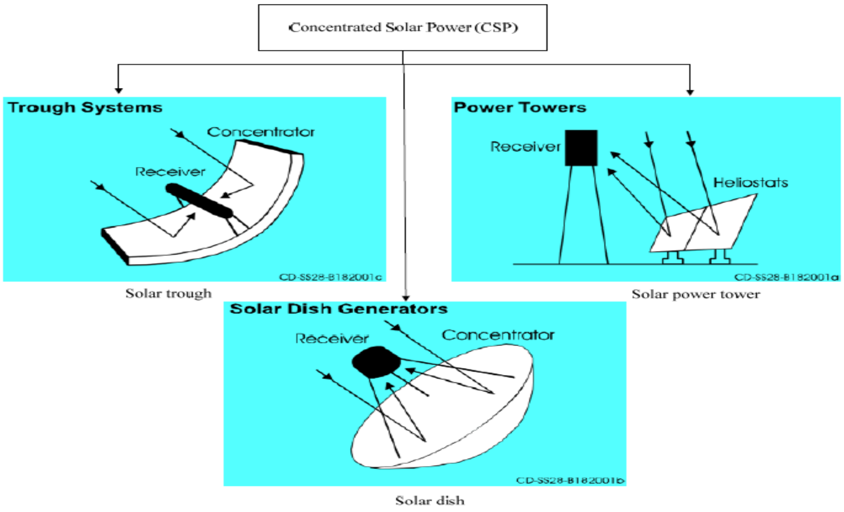


Figure 1.2: Concentrated Solar Power designs [17].

1.2.1.1 Working of a CPV System

A Concentrated Photovoltaic system works with many phenomena based on its types. A parabolic through consists of a parabola shaped mirror which act as a concentrator & a tube receiver. The mirror concentrates sunlight on the receiver tube/PV wafers. This increases the ration of Radiation hitting at that specific point.

In case of a Solar Tower system, an array field heliostat focus sunlight at a central receiver located on the top of tower. While in case of Solar Dish the mirror focuses the sunlight/radiation on the central focal point where the PV wafers are placed.

These all techniques help increasing the output of the system.

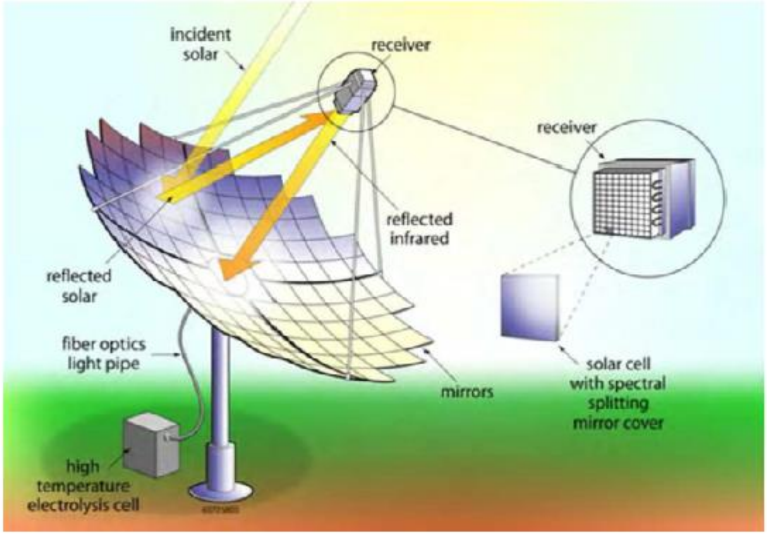


Figure 1.3: Block Diagram of a CPV System [18].

1.3 Hybrid Concentrated Photovoltaic thermal system

The idea of combining the thermal system with a traditional PV system was of two major reasons:

1. To provide cooling to the PV plate as heating decreases the efficiency [2].

2. To make the maximum use out of the solar radiations.

In order to address this problem several researches were made to get an appropriate solution of it. Many researches provided the study of the modeling of CPV/T system. [7-13]. The Authors [7] presented a design of such hybrid system, modulated it and did a performance analysis of such system. The Authors [8] studied the effect of cooling on the output of CPV/T and the effect of it on the performance co-efficient. It also studied the effects on the collector area of the Hybrid System on the performance of water collector caused due to shading of PV module. The assumed two configurations: Fully covered with the module, partially covered with the module. They compared the results with each other and with the conventional PV plate available. The Authors [9] studied as well as designed a low CPV & (PV/T) & tested it for a given spring climatic condition of the Tunisian Saharan City Tozuer, then developed & validated against the experimental results. The Authors [10] studied the effect of non-uniform flow distribution on the thermal & electrical performance of solar system by considering a PV/T collector of various designs & operating characteristics. The Authors [11] evaluated experimented the thermal & electrical performance of the a2m2 system of PVT system.

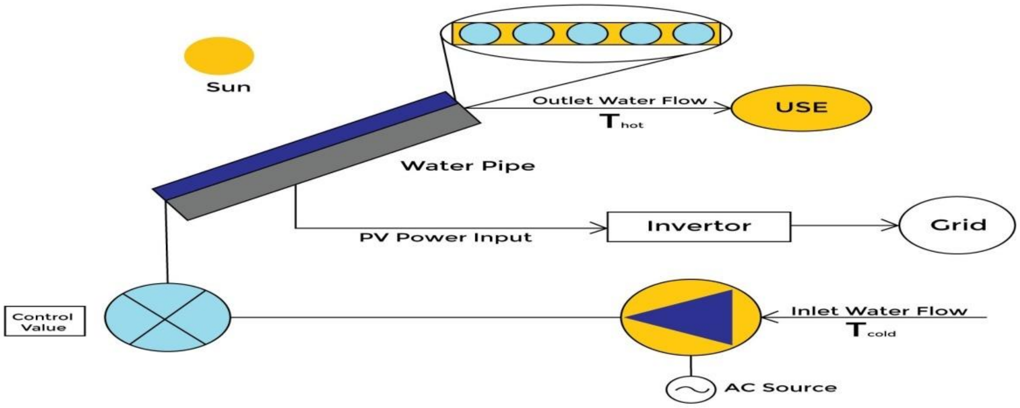


Figure 1.4: Block Diagram of CPVT system [14].

These evaluations were done for three different kinds of solar cells & the most optimum design was proposed into it. The Authors [12] evaluates the Low CPV/T system & also analyzed the effect of high temperature on the output of the system. It also different kinds of heat removal techniques were proposed. The Authors [14] models & simulates the Hybrid Solar Concentrated PV Thermal system and studies the values of Libya in a model climate. It also discusses the outcomes of available and the overall efficiency of the system increased.

1.3.1 Working of CPV/T system

In a concentrated photo-voltaic thermal system, the main priority is to enhance the output of electricity produced out of the designed system. The output of a Solar Cell depends on many variables; such as the amount of photons hitting the semi-conductor material, the efficiency of semi-conductor material, and the operating temperature. Out of these entire factors the most effecting variable is the temperature in which the system has been working. Therefore it is necessary to operate the system at as low temperature as possible in order to get the maximum electrical output out of it [13].

The highest temperature achieved by a flat plate solar panel is around 40-600’C, which is usable for the domestic heating but is of no use for any other kind of work as the temp. is not higher enough to produce steam so a small turbine could work. So in order to generate maximum electrical output as well as to generate the greater amount of thermal energy both these variables are to be carried side by side [13].

1.3.1.1 Types of Concentrating Photovoltaic

The concentrating photovoltaic (CPV) is used to refer to a system that combines photovoltaic (PV) cells with an optical component, that concentrates light with an optical component. This optical component is used to concentrate the sunlight from a greater area to a specific area of the solar cell which increases the harvest of energy from the particular solar cell.

This concentration of light is achieved by the use of Fresnel lens, parabolic trough dishes, V-through mirrors, refractive prism or a lens [15]. The output of the system also depends on the type of sunlight that is being focused.

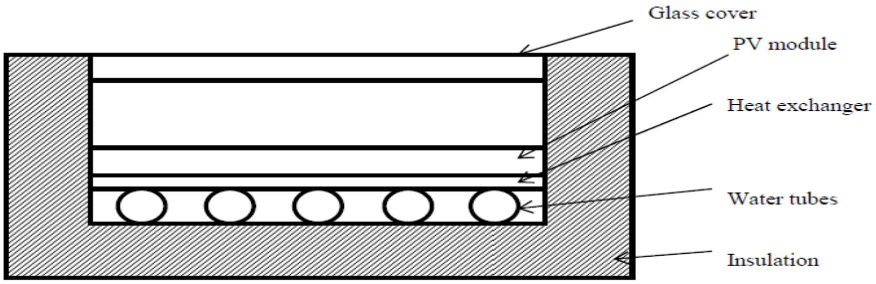


Figure 1.5: A Hybrid PV/T Collector [16].

The classification is done on the concentration factor. In a low concentrated solar system the factor is less than 10(suns), while in case of medium it is around 10-100(suns) & in case of a high concentration system the factor is around 100-1000(suns) [8].

1.3.1.2 Cooling System

The cooling of system is of primary importance in order to increase the overall output of the system. Different cooling methods have been introduced in order to keep the system cool under high concentration. The cooling system is selected on the basis of the type of concentration, for a concentration of 20 suns passive cooling system like trough system is used. As well as natural cooling & convocation is also relied upon [12]. If the concentration is around 10 or above the temperature is raised at a higher level and then the cooling needs to be done by either water cooling or by forced cooling of the cells [12].

1.4 Theoretical Working

In our proposed system we are designing a CPV//T System for the conditions of Lahore, Pakistan. The Solar Radiation at a specific longitude & latitude (31.4512, 74.291) is noted for all months of a year. These radiations are then concentrated through a parabolic through. The constraints of parabolic trough are set according to the conditions which comprises of the area, the incident angle and the angle of reflection. The concentrations ratio is varied in order to analyze the maximum value on which the maximum value of electrical and thermal output is achieved.

The Optimum temperature is kept at 25 Degree Celsius. And the area between the Parabolic through and the focal point is kept 2.5 m. The output heated Medium will be used in the thermo-electric module i.e. the Peltier Plate to produce further electricity in order to increase our net sum.

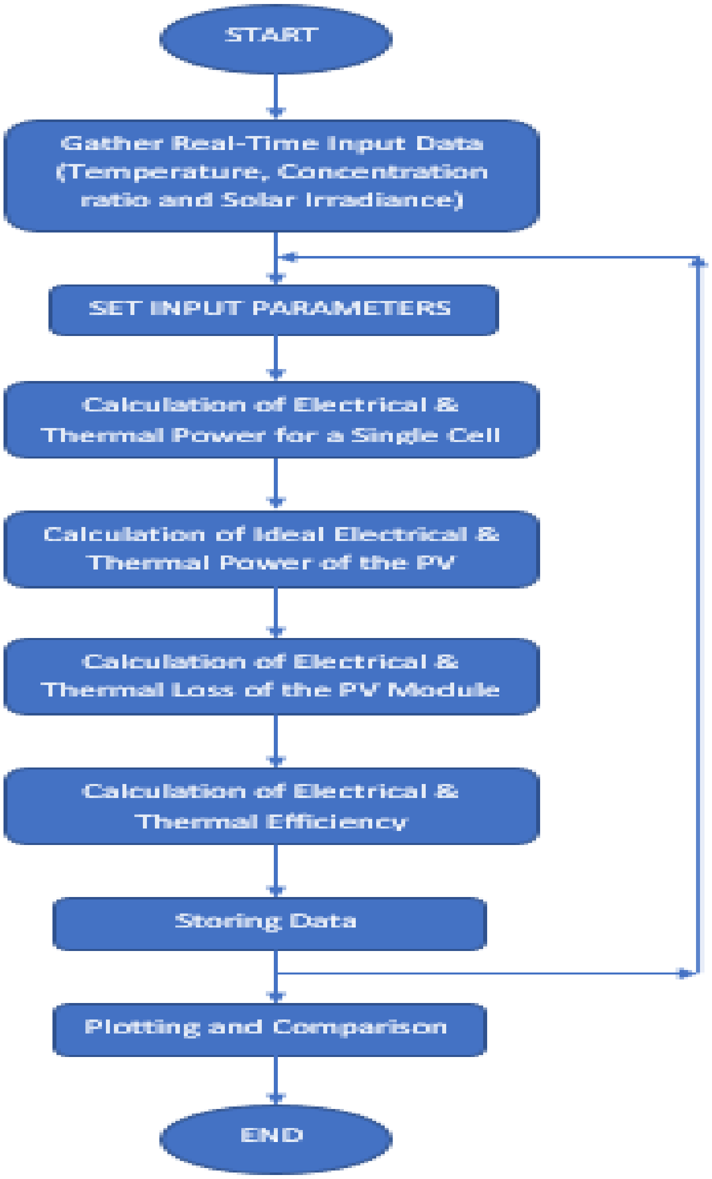


Figure 1.6: Project Flow Diagram.

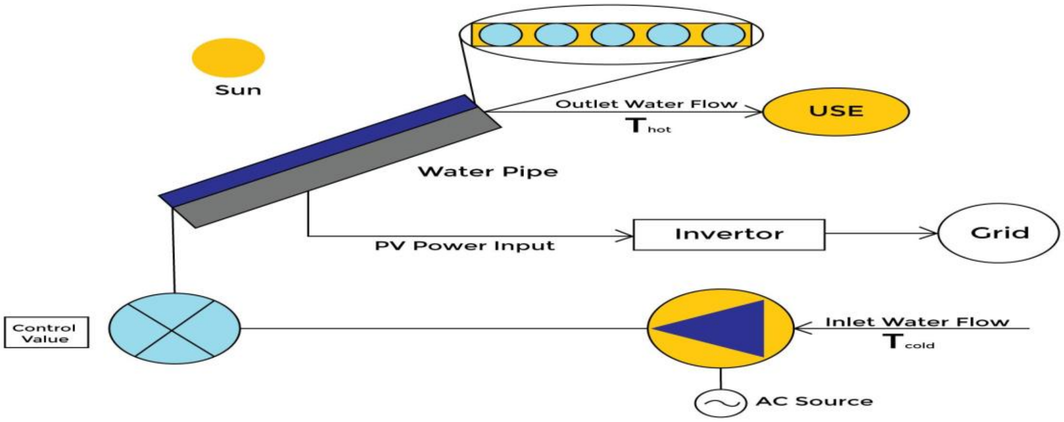


Figure 1.7: Proposed System Diagram.

1.5 Summary

In the Chapter no. 1, we discussed the Historical Background of working on this type of system. We discussed the Concentrated PV and then the CPV/T technology. In Chapter no. 2, we will discuss the Literature Review of the technology being used. In Chapter no. 3, we discussed the methodology being used in our system. Chapter no. 4 consists of Results and there comparison and Chapter no. 5 concludes the whole system.

Chapter # 2: Literature Review

2.1 Solar Energy System

Solar Energy is the heat energy of the sun. The solar energy systems utilize the energy captured from the sun and convert it to the other energies like electricity, heat and chemical energy. It is the most desirable system due to its properties of being environment friendly and automatic operation.

Figure 2.1: Solar Panel.

2.1.1 Evolution

The human nature is to improve the standard of life by utilizing the accessible things. The solar energy has been harvesting since ages for a couple of different purposes. The evolution of the solar energy utilization is categorized into the two eras as described below.

2.1.1.1 Pre-Discovery Era

Since the 6th century B.C. the solar radiations were used for lightening fire by converting the rays by means of mirror and glass while the sunrooms became common in the 4th century AD. In the year 1767, a scientist from Switzerland H. Saussure was the one to introduce the solar collectors in his findings that was made for cooking food.

2.1.1.2 Post-Discovery Era

While work with some electrolytic solution, a French scientist, A. E. Becquerel placed the solution unintentionally in sunlight which increased the electric yield to an unexpected level [21]. This is how the concept of solar cell came into existence. After the experimental invention of solar cell, many scientists gave in their efforts for studying this technology. The post discover era is sub-divided into the following six periods.

(a) Discovery

This period extends from the 1839 to 1904 AD. In this duration, the scientists were just experimenting and exploring this new tread with no understanding of the scientific knowledge and behind science. In 1970’s, Selenium was used to make solar cell which proved to be negligibly efficient [22] making its way to the experimentation of the copper solution with its oxide to be used as a photoconduction material [23].

(b) Scientific Base formation

The second period, extending from 1905 to 1950, was the one in which the scientists began to develop an understanding about the phenomenon behind solar cells. The Nobel prize winner, Albert Einstein was the one to predict the basic principle i.e. the photoelectric effect [24] followed by the emergence of the doped single crystal cell of the silicon and germanium by a scientist from Poland, J. Czochralski in 1918 and the foundation of today's PV technology was laid [25].

(c) Practical Establishment

The decade from 1950 to 1959 was the period when the practically possible ideas and the applications of PV cell were being discovered after the successful achievement of single crystal cell [26]. The methods to make use of this emerging solar technology in the space craft's and connection with grid were being introduced. Dr. D. Trivich in 1953 calculated the efficiencies based on the band gap characteristics.

(d) Improvement Era

1960 to 1980 was the time when the work on the solar energy systems was on peak. The scientists were striving hard to make the system more effective and efficient [27, 28]. By the end of this era, about 400 kW electric systems have been installed throughout the world.

(e) Developing Phase

In the developing phase, from 1980 to 2000, less work was done on the improvements and new techniques rather the previously established knowledge was practically developed. After the establishment of solar industry in USA, other countries like Australia and China also setup the industry producing PV panels. Some techniques were also introduced in that phase that were both thermally and electrically significant [29].

(f) Increasing efficiency Era

While a lot of work has been done in the previous periods, the present era is an era of continuous improvement in the efficiency of solar cells. The fed-in tariff plans, Hybrid Concentrating Photovoltaic generators and the new effective systems are being introduced. By the start of 2010, the studies show that more than 100 GW of electrical energy generated through the solar cells has been installed throughout the world [30]. The maximum of these installations was at the rooftop.

2.1.2 Importance

The solar power extraction is of great significance in many ways. It is a technique that comes with a wide range of benefits concerned with the economy as well as the ecology. Due to the great benefits, the government of many countries is taking steps to install this system on National basis [31]. The following details are found as the most promising factors.

2.1.2.1 Reliable

The solar powered systems are highly reliable and pledge to provide the ratted output for years. The simplicity and longer lifespan as compared to other renewable resources gives it an extra advantage.

2.1.2.2 Easy Installation

The main challenging task is the designing and fabrication of solar panel which has been made easy by the robotic technology. Once manufactured, the installation is not a difficult task and system operates on its own.

2.1.2.3 Eco-Friendly

The solar system has no by-product or any kind of waste. This means this system is free from all kind of pollution, including the noise pollution; having no impact on the environment and making the system eco-friendly.

2.1.2.4 Negligible Maintenance

Almost all the components of the solar system are electronic in nature which means the maintenance is not required. Although, simple cleaning and dusting of solar system is mandatory for its proper functioning.

2.1.2.5 Cost-Effective

The chief investment of the system is the buying cost. As this system requires no maintenance, no other cost is expected except the one associated with the storage system (battery bank) or the invertors etc. So, it has low maintenance cost.

2.2 Harvesting Solar Power (Solar Technologies)

The solar energy can be harvested in many ways. For ages, the people have been utilizing the solar energy. The techniques which convert the solar energy to electric energy can be classified in the following two types:

1. Direct Conversion
2. Indirect Conversion

2.2.1 Direct Conversion

2.2.1.1 Solar Energy to Electrical Energy

This method is also known as the Direct Conversion of electricity. The sun rays are incident on a special material which can generate the energy carriers. The photons whose band gap energy is larger than that of the semiconductor material, permits the charge carriers to move in their conduction band. The charge carriers start to move to their respective electrode and when these two electrodes are connected physically through an electrically conducting material, the electronic current starts to flow [32].

The solar energy conversion system consists of the following components:

1. ***Solar Array***
2. ***Charge Controller***
3. ***Inverter***
4. ***Battery***

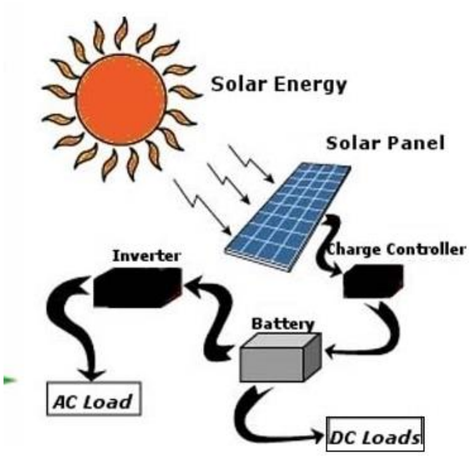


Figure 1.2: Direct solar Conversion.

The efficiency of this technique depends upon the minority charge carriers that make their way to the junction without combining with the opposite charge carrier. Different strategies are being developed so that the efficiency is increased. These improvements include the photon absorption, charge separation, transportation and collecting the charge carriers.

2.2.2 Indirect Conversion

The indirect conversions firstly convert the solar energy into some other energies; chemical energy and heat energy, afterwards converting them to the electricity. Using the indirect conversions the efficiency of the system increases [33].

The indirect conversions are as follows:

2.2.2.1 Solar Energy to Chemical Energy

The solar energy can be used to generate the chemical energy. The chemical fuel is obtained which can be utilized in a variety of applications. The generation of the chemical energy uses a solar concentration of about 5 to 5000 suns. The temperature ranges from a few hundred to several hundred Celsius. There are basically three processes in this domain which are as follows:

(a) Photosynthesis

Photosynthesis is a naturally occurring phenomenon in which the sunlight produces the chemical energy. The green plants use this method to prepare their food where the water and carbon dioxide are converted into the energy and oxygen in the presence of chlorophyll, a pigment, and the sunlight. This energy is basically stored in the form of biomass which is taken up by the other organisms. It doesn’t have any role, either directly or indirectly, in the electricity generation.

(b) Artificial Photosynthesis

Inspired from the biological process of photosynthesis, the scientists worked on mimicking this phenomenon for the fuel generations. It is a complex method that uses the direct conversion of water and carbon dioxide in the presence of a catalyst and sunlight to produce the combustible gasses such as hydrogen, methane and ammonia etc. These gases are sent to the gas grid storage where they are used for either the heating purposes or sent to the power plants for the generation of electricity

(c) Thermo chemical Routes

In this process, mostly the semiconductor materials are used. The material is heated by means of the solar radiations till they are heated at a certain level of temperature. Then the material is reacted with steam or carbon dioxide yielding pure water, carbon mono oxide and a large amount of energy. This energy can be utilized for many applications.

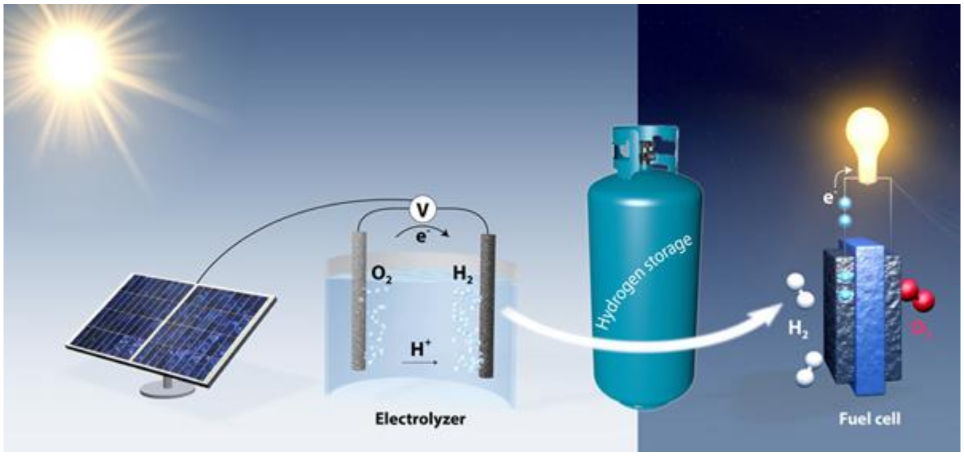


Figure 2.2: Solar Energy to Chemical Energy Conversion.

2.2.2.2 Solar Energy to Thermal Energy

The solar energy to thermal energy conversion devices are also known as the concentrator devices. The increase in temperature and more energy is generated. The thermal energy is converted into the electrical energy by means of thermal engine, synchronous generators, thermionic devices, thermo philic devise or the thermoelectric generators.

2.3 Optical Methods for Solar Concentration

2.3.1.1 Parabolic Trough

It is the single axis tracking mirror which concentrates the solar radiations on the receiving tubes Which contains the heat transfer fluid to transfer the captured heat energy at a temperature range of about 400 ^{0}C. These tubes are made of a metal and placed in a covering of a glass tube so that there is a minimum loss of heat from the tube. Heat-exchangers are there to capture the heat from the tube and process it further so that the superheated steam is generated. This generated steam powers the conventional turbine generator. Technologies are being trending so that the direct steam can be generated by the solar panel.

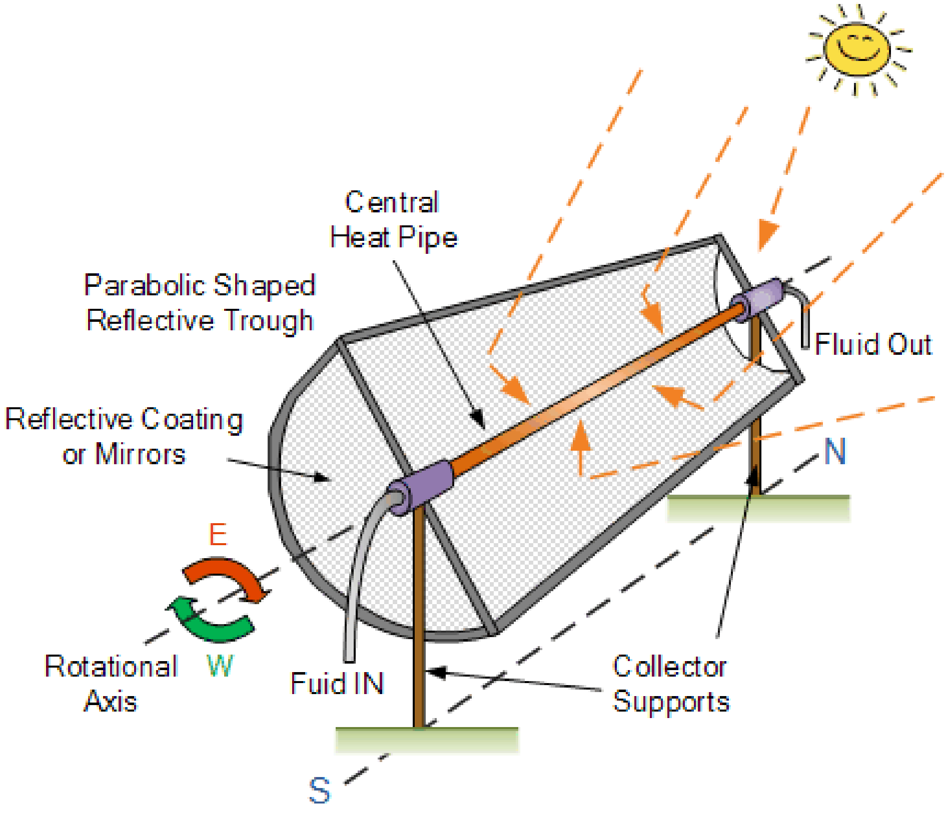


Figure 2.4: Parabolic Trough.

The overall efficiency of the system depends upon the individual efficiencies of collector, field and the steam cycle. The collector efficiency depends upon the ray angle and the temperature of the tube. The maximum collector efficiency is 75% while the field loss is always below 10%. The conventional system of the steam cycle has an efficiency of 35%.

2.3.1.2 Field of Heliostats (Tower Concept)

The power tower consists of numerous dual axis mirrors, known as heliostats, around the tower. The task of all the heliostats is to focus the sunlight on a specific point on the tower equal to about 100 to 10000 suns. The temperature recorded at the top of the tower is approximately 200 to 3000 degrees centigrade. Heat carriers used for the Power tower mostly consists of the hot air or the salt in molten state.

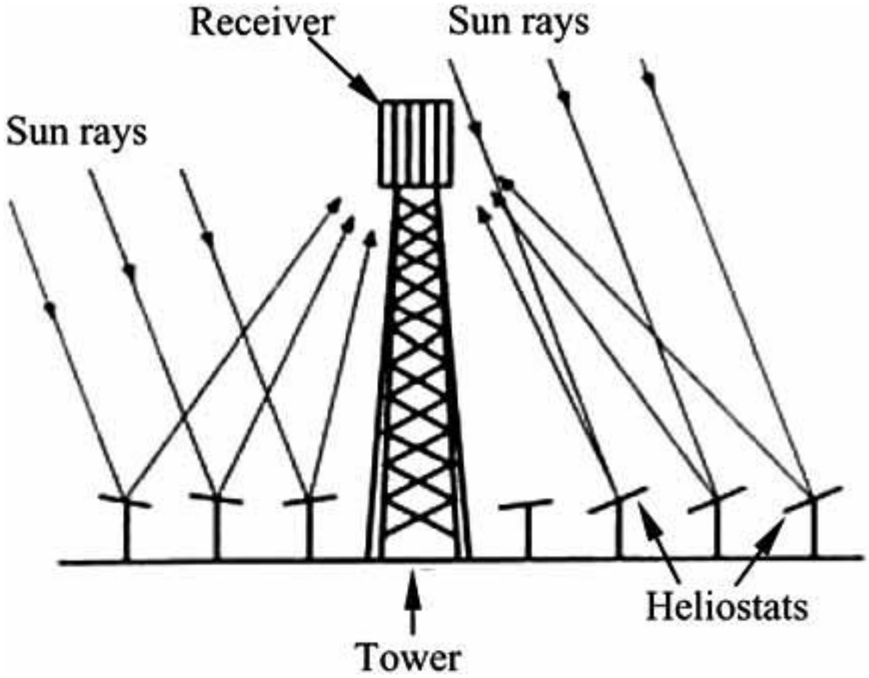


Figure 2.3: Power Tower.

The generating capacity of this technique is about 30 to 400 MW. The efficiency of this system depends upon the temperature of the receiver. The temperature is a function of many factors including the solar radiance, the optical properties, the cleanliness of the heliostats, wind, humidity and the accuracy of the tracking.

2.3.1.3 Solar Dish

The solar dish utilized the old concept of conventional dish to catch the signaling waves. It consists of the concave mirror which is a dual- axis tracked one. The receiver is placed at the point of focus. The temperature is of the range of 400 to 1500 degree Celsius. This heat is used to generate the electrical energy via thermal engine. This system has high capital cost which makes it to be used less.

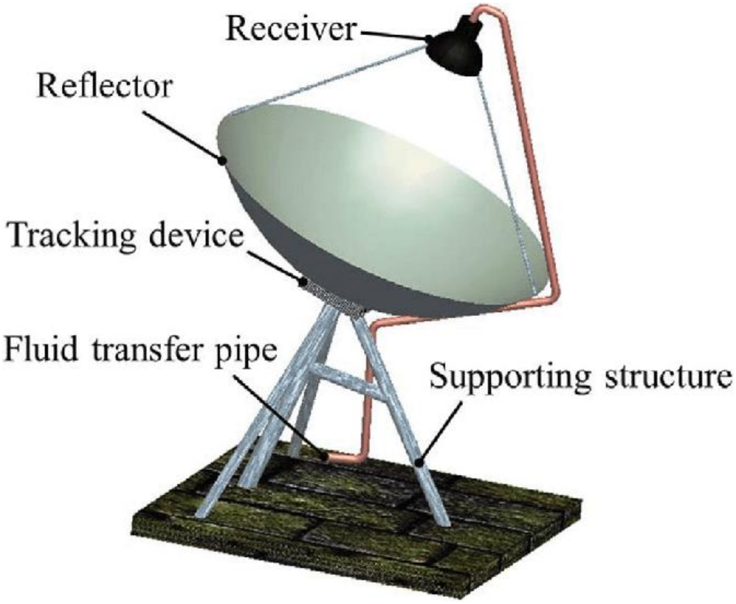


Figure 2.4: Solar Dish.

2.3.2 Comparison of Solar Concentrators

Each of the solar concentrator has its own merits and demerits. Keeping in view the working temperature and the compatible heat transfer carrier, these optical concentrators are used. The following table explains the solar concentration comparison in terms of the temperature and the heat carrier.

Table 2: Solar Concentrators.

Solar Concentrators	Heat Carrier	Temperature Range (1000 ^{o}C)
Parabolic	Salt Solution, Oil, Water	0.3 - 0.55
Field of Heliostats	Salt Solution, Air, Water	0.3 – 1
Solar Dish	Sterling Engine	0.4 - 1.5

2.4 Hybrid CPV/T

The hybrid concentrator photo voltaic and thermal system establishes an efficient two in one kind of generation. The increase in temperature adversely affects the efficiency of the system. The open circuit voltage varies inversely with the ambient temperature. For instance, in case of the silicon semiconductor, the efficacy drops almost 0.4% with the increase of temperature by one degree. The hybrid CPV/T systems are designed to utilize the excessive heat without compromising the efficiency of the system. The system consists of the PV cells along with the thermal collectors.

2.4.1 Significance

This system is significant in the following ways:

1. These systems are efficient both in terms of producing the electrical energy and capturing the heat energy, which can also be used in the electricity production.
2. This system cools the system and transfers the heat away. The lower the temperature, the more efficient will be the system.
3. It can produce two energies in one footprint.

2.4.2 Classification w.r.t concentration factor

Based on the concentrator factor of the reflecting radiations, the CPV/T systems are classified as follows (Voorthuysen, 2005):

2.4.2.1 Low Concentration

In this kind of system, the solar concentration is normally less than 10 suns. This type of system doesn’t need any external cooling system. Rather, the natural automatic cooling occurs.

2.4.2.2 Medium Concentration

Medium concentration systems have the concentration ratios between 10 and 100 suns. They need a forced cooling provided by an external medium.

2.4.2.3 High Concentration

The high concentration systems have the concentration ratio above 100 suns, normally between 100 and 1000 suns. They need a forced cooling provided by an external medium through the pipes and conduits.

2.4.3 Classification w.r.t Collector

On the basis of the type of collector, the CPV/T systems are divided into the following two types:

2.4.3.1 Flat Plate Collector

These types of collector’s looks like a flat plate thermal collector. On the top of these collectors, is the PV panel which consists of a PV Module, glass covering and an absorption plate [34]. This type of collector is further classified into the following three types based on the heat transfer material.

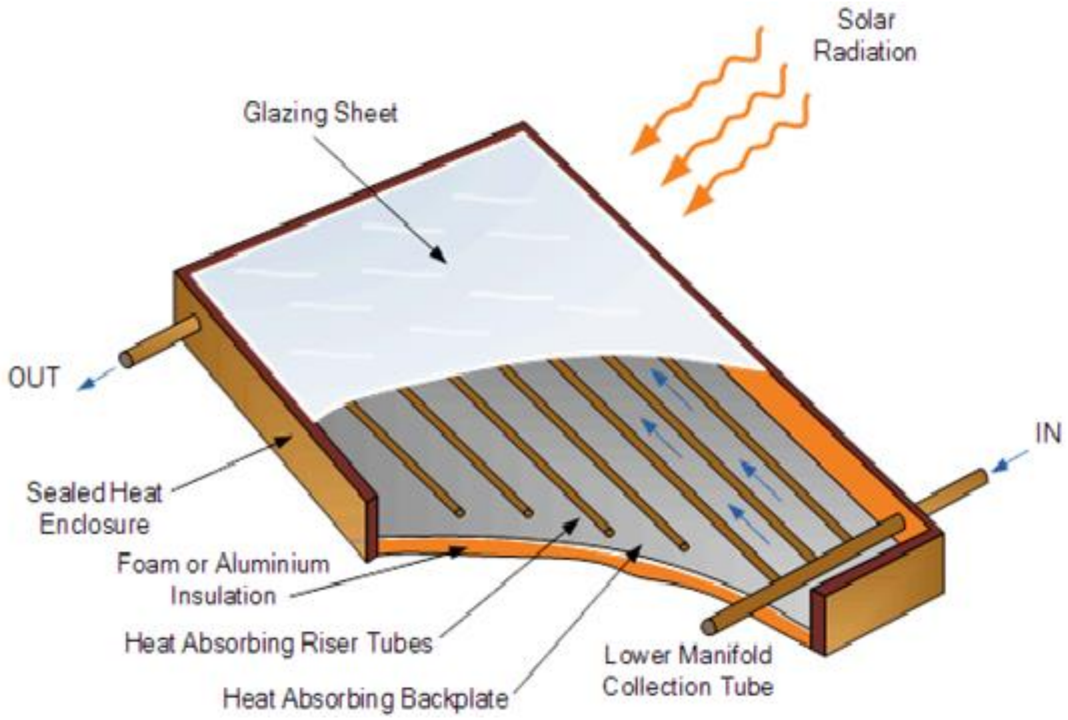


Figure 2.5: Liquid-type CPV/T.

(a) Liquid-Type CPV/T

It has the water of a solution of glycol for the cooling purposes. It is mostly used in the places where the hot water is needed and this water can be temporarily stored in the large tanks. This type of CPV/T system can be installed on the top of the buildings. The negative points of this system are in that it can cause the leakage or the cooling material may freeze in the extreme conditions [35].

The liquid type CPV/T systems can be glazed; having glass covering, or unglazed; without covering. The former ones provide the less heat loss but the latter ones provide good electrical properties but are somehow, thermally inefficient.

(b) Air-Type CPV/T

This type of the system which uses air circulates and provides the cooling effect. It comes with low cost and have no risk associated with the degradation of the medium i.e. no freezing or boiling issue. It also needs the heavy volume of air to provide the system heating which means that the high capacity; large and bulky pipes are needed for this system and this system cannot be used for the small-scale applications. Moreover, it has low thermal performance.

(c) Combination of Liquid/ Air CPV/T

The modern technologies mainly focus in “two-in-one” kind of systems which cove the disadvantages of both the systems. This system uses both the water and air as the heat carrier. In this combination, the water-type cycle should be designed properly i.e. the tubes, channels, absorber etc. should be made system compatible and climate specific.

2.4.3.2 Concentrator Collector

Instead of the flat plate, this system utilizes the optical concentrators which collect and reflect the sun rays and focus them on a specific area. It comprises of the central heat pipe (CHP) through with the carrier medium is passed [36]. This medium can be air, water of molten salt. The rays are concentrated such that they fall on the PV cells to generate electrical energy and on the heat carriers to heat the fluid.

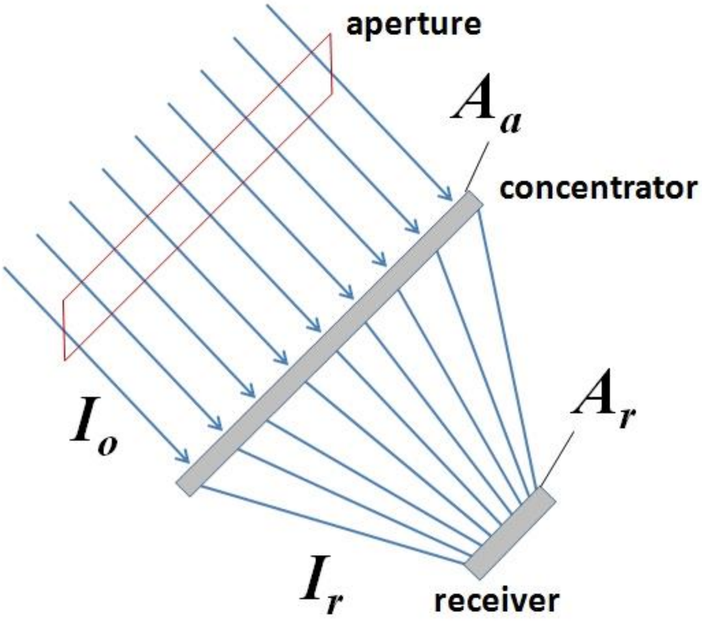


Figure 2.6: Working of Concentrator Collector.

These collectors make use of the reflector and thus less photovoltaic material is used which reduced the cost. The less expensive material replaces the expensive material.

As the solar radiations are concentrated on a single point which means that the temperature of that point will be enormously high; damaging the material. Thus, an effective cooling will be needed for the system [37]. But too much cooling can also be an issue, so special calculations are required. This type of collectors also needs the tracking system and due to its bulky size, it is not implemented on the small-scale implementations. Additionally, it cannot stand the winds and the dust.

2.5 Charge Controller

The charge controller is a device which connects the PV module with the battery. It open and closes the circuits and allow the battery to be charged on a specific rated voltage. The techniques on which a charge controller works is listed as follows:

1. PWM
2. MPPT

2.5.1 PWM

It stands for the Pulse Width Modulation. In this technique, a carrier signal is provided which controls the charging of the battery.

2.5.1.1 Working

It uses a PWM signals upon which the generated waveform rides. First, the PWM based charge controller at the maximum generated current so that the nominal voltage is reached. Once the voltage level is maintained, the controller disconnects the array of solar panel with the battery.

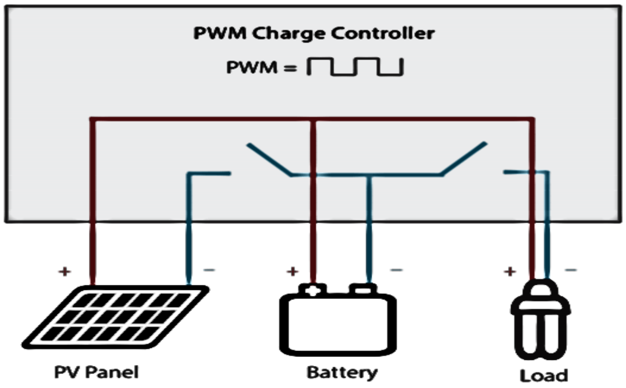


Figure 2.7: PWM based Charge Controller.

The operation of PWM based charge controller is closer to the maximum working power point but it exceeds the values somehow. The following figure shows the graphical representation describing the maximum and minimum voltage levels of the charge controller. The voltage level is maintained, increasing the efficiency of the solar panel but the maximum power point is not reached.

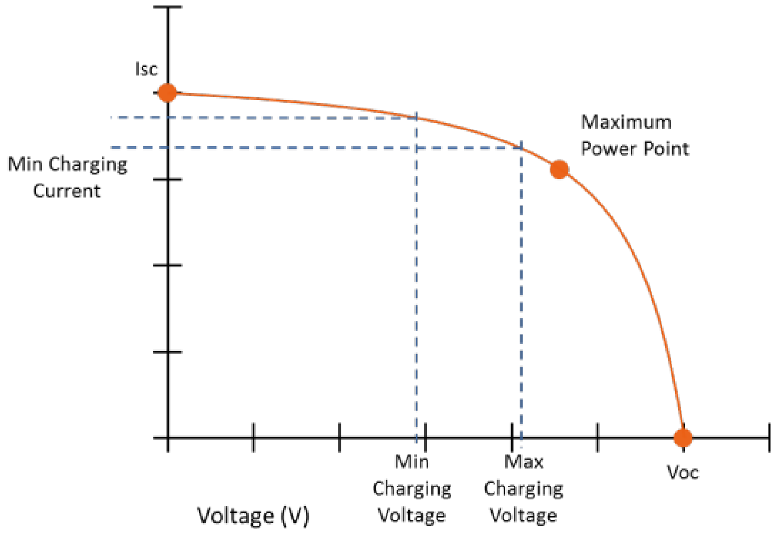


Figure 2.8: Characteristics of PWM Charge Controller.

2.5.1.2 Merits

i. It is a time-tested technology. A study shows that the systems installed with the MTTP charge controllers over a period of three decades have been working properly, with negligible efficiency decrement.

ii. It is a cheap solution to operate the system near maximum power point.

iii. This system has the ability to deal with the current range up to the maximum of 60 Amperes

iv. It can work for the variable system capacities. Thus, the PWM based charge controller comes in a variety of sizes

2.5.1.3 Demerits

i. Special care should be taken to select the voltage rating of this controller. The input voltage from the solar panel should be equal to the battery bank voltage
ii. This system is not capable of dealing with the high voltages which makes it problematic to be used on the grid-connected applications.
iii. It cannot work with a solar panel array exceeding 60 cells per panel.

2.6 Objective of Project

The objective of the project is to meet the following conditions

1. The designing of a hybrid CPV/T system which is efficient in terms of both the direct electric generation and the conversion of solar energy into heat energy which runs the turbine.
2. Keeping in view the above point, the maximum extraction of energy using the solar concentration ratio is done so that the solar energy can be utilized at maximum.

Table 3: Reference Site & System Conditions

Description	Parameter
Ambient Temperature	30*C
Ambient Pressure	1013.2mbar
Ambient Humidity	50%
Input Fluid Temperature	25*C
Optic Efficiency of Parabolic Trough	0.85
Heat Exchanger Thickness	2*10^-3m

2.7 Cost Analysis of PV and CPVT Systems

The solar radiation increase the temperature of PV modules and natural cooling by radiation and wind convection is not sufficient to reduce their temperature sufficiently, resulting in a drop of their electrical productivity. This unwanted impact can be partially avoided by heat extraction with a proper fluid flow and the decrease of PV module temperature can be joined with a useful fluid heating. Hybrid Photovoltaic/Thermal (PV/T) solar systems can give electrical and thermal output at the same time, achieving a higher energy conversion rate of the absorbed solar radiation. PV/T systems consist of different PV modules simulate to heat extraction devices, by which outsourced air or water of lower temperature than that of PV modules is heated by cooling them [19].

Hybrid PV/T systems are of higher expensive than standard PV modules due to the expansion of the thermal unit and therefore a cost/benefit analysis is needed to discover the limits of practical utilization of these. Hybrid PV/T systems with air heat extraction are more widely studied due to their easier construction and operation. Water heat extraction is more costly, but water from mains is generally under 20 ºC and therefore in many applications water heating is useful during all seasons. PV/T systems with air or water heat extraction could be cost-effective if the extra cost of the thermal unit is low and the extracted heat is effectively utilized.

The performance of 1 kW PV system has examined using PVsyst software. The initial cost of the considered system is approximately 4434 USD. The capital cost of the CPVT system is the sum of different components costs that were added in experiment. The capital cost of the CPVT system is calculated on the base of the different invoices from international and local solar suppliers, approximately 6099.4 USD. The present cost of the system is the result of summation of capital and installation costs [19].

Table 3: Cost of PV Solar System [19].

Components	**Cost in US($)**
PV Solar cells	1265
Lens	337.5
Solar Tracking System	1012.6
Battery Bank	843.6
Flow Meters	84.8
Inverter	168.8
Charge Controller	421.7
Installation labor	300
Total Cost	**4434 $**

Table 4: Cost of CPVT Solar System [19].

Components	**Cost in US($)**
PV Solar cells	1265
Lens	337.5
Solar Tracking System	1012.6
Battery Bank	843.6
Flow Meters	84.8
Inverter	168.8
Charge Controller	421.7
Thermal Storage System	548.5
Cooling System	195
Absorber & Supporting Frame	421.9
Thermocouple	80
Installation Labor	420
Total Cost	**6099.5 $**

Chapter # 3: Methodology

The simulation works on the mathematical modeling of the solar parabolic trough system. The system models a parabolic trough solar concentrator which concentrates the solar radiation on a specific area. These radiations are more powerful than the incident sun rays which can be used to generate electricity directly or heat the working fluid, the heat of which can be extracted further for increasing the electricity generation for our system through Peltier Plate and other functions.

First of all, the mathematical equations were converted into the subsystems using the MATLAB SIMULINK software. These sub-systems were connected according to the mathematical dependence.

Real-time data for the direct solar irradiance and the angle, at which the sun rays are incident on the parabolic trough, was gathered from the original website of The National Aeronautics and Space Administration with the acronym NASA. These values are stored in a spreadsheet and then connected to the SIMULINK environment by mean of a special “from file” block.

The simulation of the modeled system was observed after changing the value for the concentration ratio in various given conditions and the output data points were saved in another Excel file.

The stored Excel files having the data for the controlling variables of the parabolic trough solar concentrator were analyzed, and the input parameters were compared to obtain the optimal working conditions.

3.1 Modeling of the System

The system of this research work was modeled in the MATLAB Simulink Environment. It represents the mathematical modeling of the parabolic trough for the solar radiation concentration. The model consists of the various blocks in the order of the chronological dependence on the values of the output power in the terms of the Electrical power and the Thermal power.

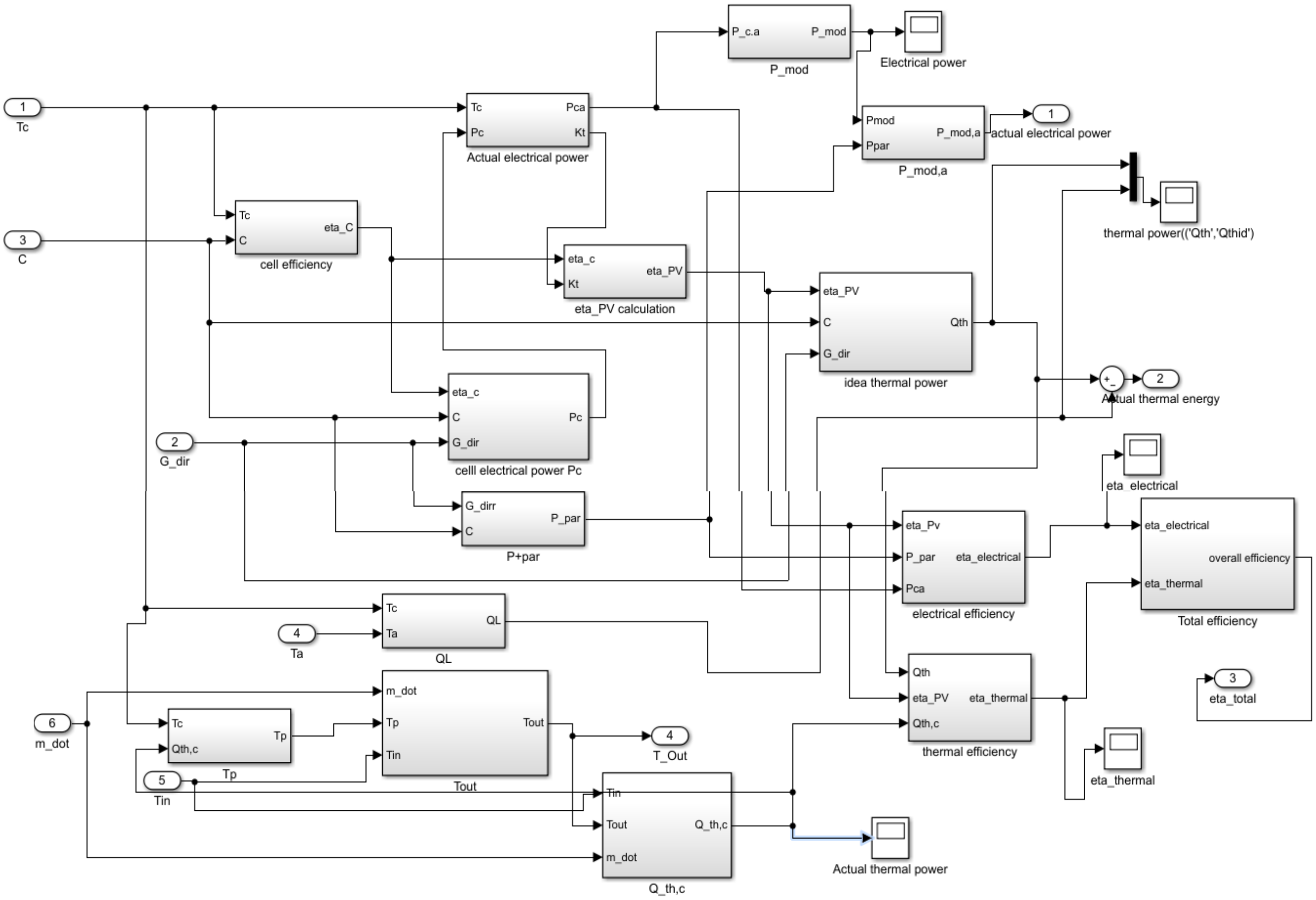


Figure 3.1: Studied Model in MATLAB.

3.2 Input Variables

In the designed system, those input variables chosen which practically affects the output of the system. The input variables are listed as follows:

3.2.1 Direct Irradiance

The constant emission of solar radiation as a result of the fusion reaction in the surface of earth is known as the solar radiation. Before reaching the surface of Earth, some of the radiations diffuse in the space; this is known as the diffused radiation. The radiations which reach the earth’s surface without being diffuse are known as the direct radiation. The value of direct radiation at a particular area varies with the distance of sun from that area and the incident angle.

NASA has been recording the value of solar radiation for ages. The data for the direct solar radiation has been taken from the NASA website for the various months of the year 2018 with reference to different incident angles. The values of the solar radiation at various angles for a year is taken from the NASA website and noted as in the following table.

Table 5: Direct Irradiance w.r.t Incident Angle.

Month	**0 º**	**16 º**	**31 º**	**46 º**	**90 º**
January	3.25	4.12	4.69	4.98	4.12
February	4.09			5.5	4.11
March	5.35			5.94	3.59
April	6.38	6.62	6.44	4.9	5.35
May	7.31	7.16	6.61	5.93	6.11
June	7.22	6.94	6.28	5.36	1.7
July	6.09	5.93	5.46	4.76	1.85
August	5.66	5.7	5.42	4.9	2.21
September	5.47	5.88	5.92	5.63	3.17
October	5.02	5.92	6.4	6.5	4.61
November	3.93	5.02	5.72	6.07	4.96
December	3.21	4.22	4.92	5.31	4.59

3.2.2 Incident Angle

The incident angle is the angle of the radiation w.r.t the normal to the solar parabolic trough solar concentrator. This incident angle lays the basis of the reflected ray to the PV medium. The values for the incident angle can be a dominant factor effecting the efficiency and optimal working of the parabola trough solar concentrator.

3.2.3 Temperature

The temperature of the input fluid is also one of the important factors for the proper functioning of the solar concentrator. The value of the fluid temperature at the input stimulates the fluid temperature at the output.

3.2.3 Parabolic Trough

The value of focal length (**a**) of the parabolic trough has a key effect on the output of the system. The value of (**a**) helps in deciding the value of internal reflection angle which aid in determining the value of **C** the Concentration Ratio.

3.3 Operational Definition of Components/ Modules

There are series of factors affecting the output of the proposed system. The details of the attributes of these different components used to design the studied model are discussed as follows:

3.3.1 Single Cell Electrical Efficiency

The first step in the mathematical modeling is the calculation of the single cell efficiency which depends upon the concentration ratio. The single cell efficiency determines the number of the cells, arrays and panels to be used for attaining the required electrical power.

3.3.1.1 Mathematical Formula

The mathematical formula for the electrical efficiency of a cell depends chiefly on the parabolic trough characteristics. The temperature of the cell and the value of the concentration ratio of the trough which varies with the value of Concentration ratio which is defined as the aperture ratio between the parabolic trough to that of the absorbing medium that is the solar collector with PV medium. Mathematically, it is given by the following formula.

$$\eta_c = 0.298 + 0.0142 \times \ln C + (-0.000715 + 0.0000697 \times ln\, C)(T_c - 25) \qquad 3.1$$

Where,

η c = cell’s electrical efficiency

C = Concentration ratio

Tc = cell temperature

3.3.1.2 MATLAB Sub-System

The following subsystem block was designed in the MATLAB SIMULINK environment. The input factors are the cell’s temperature and the concentration ratio while the output in terms of the cell’s electricity is obtained.

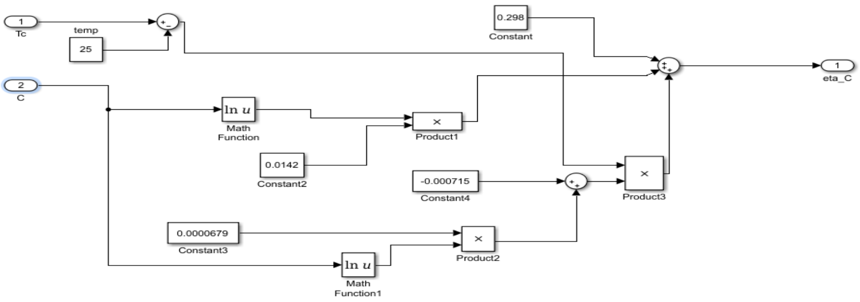


Figure 3.2: MATLAB Subsystem for Single Cell Electrical Efficiency.

3.3.2 Electrical Power for a Single Cell

After obtaining the value of the cell efficiency, the electrical power for a single cell is calculated. The more the electrical power of a single cell, the less number of arrays are required for pulling off the designed power system.

3.3.2.1 Mathematical Formula

The mathematical formula for calculating the electrical power of a single cell is given as follows:

$$P_c = \eta_C \text{ x } \eta_{opt} \text{ x } A_C \text{ x } C \text{ x } G_{ind} \text{ x } f \quad 3.2$$

Where,

P_c = Electrical power of a single

η_C = Single cell efficiency

η_{opt} = Optical Efficiency

A_C = Area of a single cell

C = Concentration ratio

G_{ind} = Direct radiance

f = Non-ideal factor

3.3.2.2 MATLAB Sub-System

The Subsystem designed in the MATLAB SIMULINK environment is as follows;

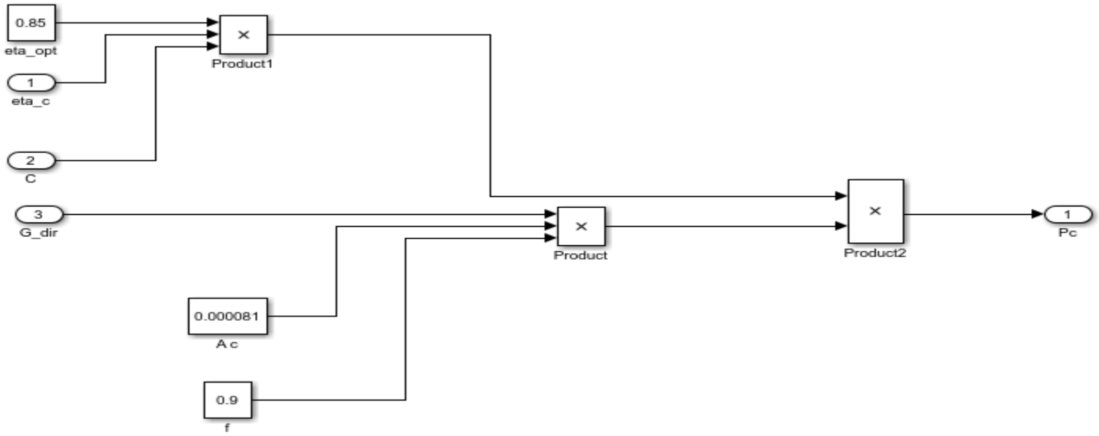


Figure 3.3: MALAB Subsystem for Electrical Power for a Single Cell.

3.3.3 Actual Electricity Delivered by PV Cell

The actual power delivered by the solar cell depends upon the electrical power of a single cell and the input temperature of the cell.

3.3.3.1 Mathematical Formula

Mathematically, the actual electrical power delivered by a photovoltaic cell is represented as follows;

$$P_{c,a} = K_t \times P_a \qquad 3.2$$

$$K_t = 1 + \alpha(T_c - 25) \qquad 3.3$$

Where

$P_{c,a}$ = Actual electrical power of the cell

K_t = Temperature's correction coefficient

T_c = Cell's temperature

3.3.3.2 MATLAB Sub-System

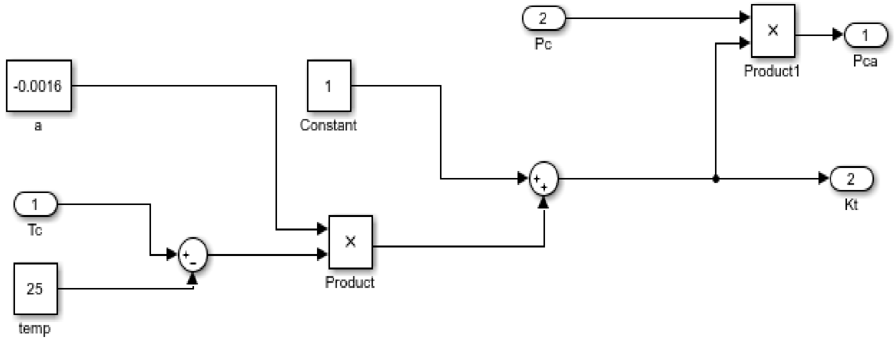


Figure 3.4: MATLAB Subsystem for Actual Electricity Delivered by PV Cell.

3.3.4 Ideal Electrical Power of the PV Module

The ideal electrical power is the maximum theoretical power that can be obtained from the PV module.

3.3.4.1 Mathematical Formula

The mathematical formula for the ideal electrical power is given in the following mathematical equation;

$$P_{mod} = N_c \times P_{c,a} \times \eta_{inv} \qquad 3.4$$

Where,

P_{mod} = Ideal electrical power of PV module

N_c = No. of cells in the PV module

$P_{c,a}$ = Actual power of a single cell

η_{inv} = Inverter efficiency

3.3.4.2 MATLAB Sub-System

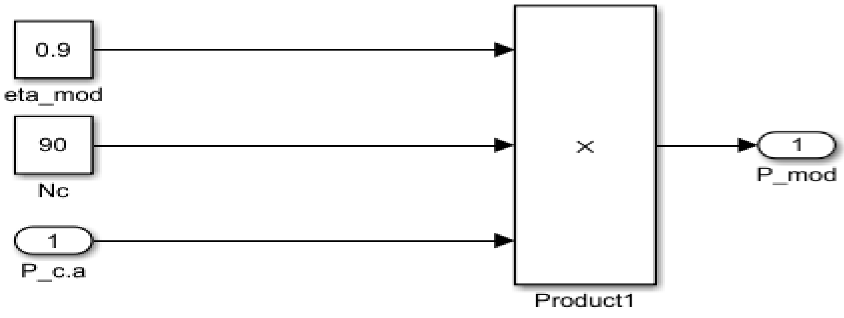


Figure 3.5: MATLAB Subsystem for Ideal Electrical Power of the PV Module.

3.3.5 Electrical Power Loss of the PV Module

Due to some practical factors, the value of the obtained electrical power differs to that of the calculated theoretical power. The loss of the electrical power per module is calculated so that the calculations can be made more efficient and maximum yield can be obtained.

3.3.5.1 Mathematical Formula

The mathematical formula is given by;

$$P_{par} = G_{par}.G_{ind}.A_c.C.N_c \tag{3.5}$$

Where,

P_{par} = Module loss

G_{par} =Losses factor

G_{ind} = Indirect radiance

N_c = No. of cell

3.3.5.2 MATLAB Sub-System

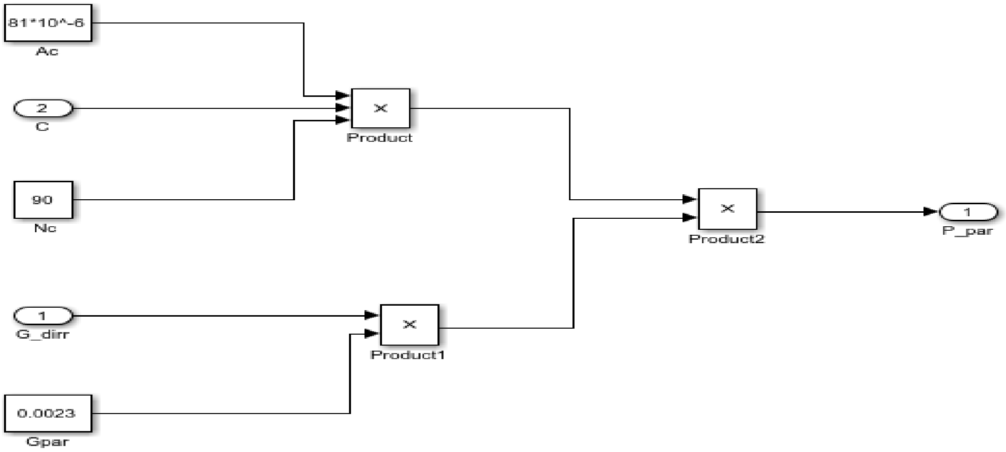


Figure 3.6: MATLAB Subsystem for Electrical Power Loss of the PV Module.

3.3.6 Actual Electrical Power of the PV Module

3.3.6.1 Mathematical Formula

$$P_{mod,a} = (P_{mod} - P_{par}).\eta_{inv} \qquad 3.6$$

$P_{mod,a}$ = Actual electrical power of the PV module

P_{mod} = Ideal power of the module

P_{par} =Module loss

η_{inv} = Inverter efficiency

3.3.6.2MATLAB Sub-System

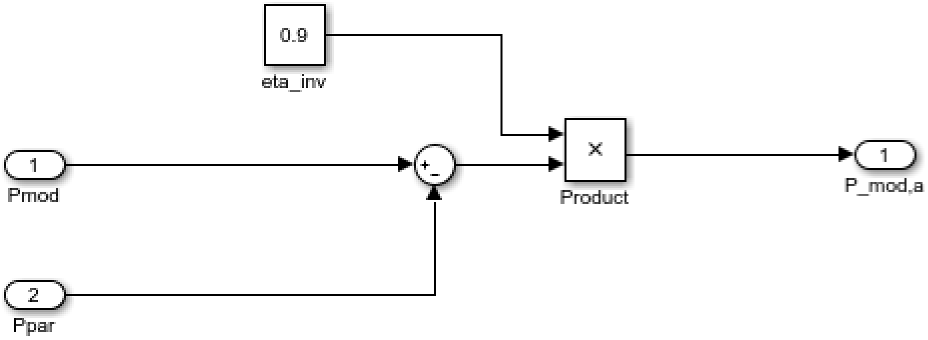


Figure 3.7: MATLAB Subsystem for Actual Electrical Power of the PV Module.

3.3.7 Electrical Efficiency of PV Module

In the next step, the electrical efficiency of the whole PV module is calculated which is described in terms of the efficiency of the module, efficiency of the single PV cell and a constant value Kt which is defined as the temperature correction coefficient.

3.3.7.1 Mathematical Formula

$$\eta_{pv} = \eta_c . \eta_{mod} . K_t \qquad 3.7$$

Where

η_{pv}= Electrical efficiency of PV module

η_c= Cell's efficiency

.η_{mod}= electrical efficiency of the module

K_t= Temperature correction coffecient

3.3.7.2 MATLAB Sub-System

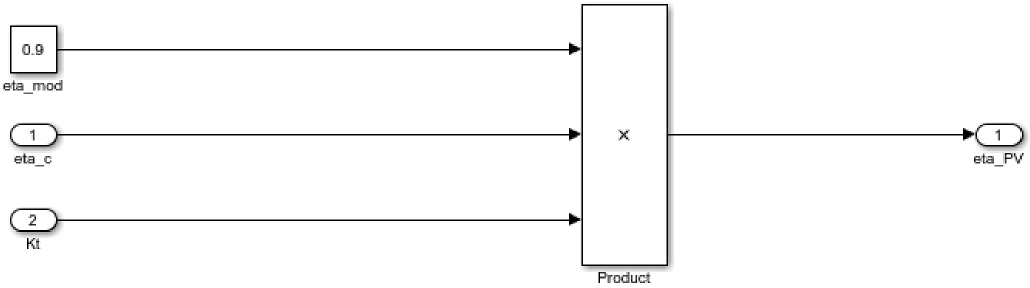


Figure 3.8: MATLAB Subsystem for Electrical Efficiency of PV Module.

3.3.8 Ideal Thermal Energy of PV Module

Along with the generation of the electrical energy, the parabolic trough solar concentrator also yields thermal energy. This thermal energy can be used directly for the domestic heating purposes or indirectly for the generation of electrical power by steam generation or other methods.

3.3.8.1 Mathematical Formula

$$Q_{th} = (1 - \eta_{pv}).\eta_{opt}.C.(G_{ind}.f).A_c.N_c \qquad 3.8$$

Q_{th} = Ideal thermal energy

η_{pv} = efficiency of PV module

η_{opt} = Optical efficiency

G_{ind} = Direct radiance

f = nonideal tracking factor

A_c = Area of an individual cell

3.3.8.2 MATLAB Sub-System

The MATLAB system for the calculation of this parameter of ideal thermal power is designed as follows:

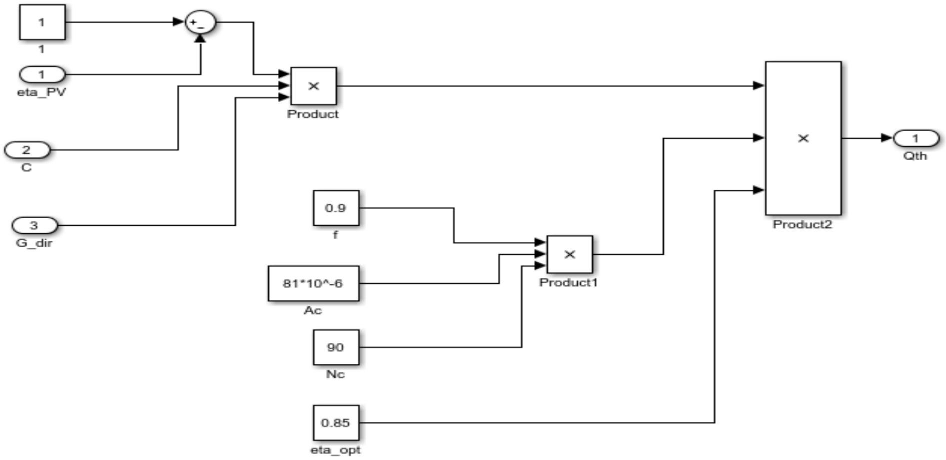


Figure 3.9: MATLAB Subsystem for Ideal Thermal Energy of PV Module.

3.3.9 Heat Loss through Radiation

Owing to some practical factors, the value of the yielded thermal power differs to that of the calculated theoretical power. The loss of the thermal power per module is calculated so that the calculations can be made more efficient and maximum possible output is expected.

3.3.9.1 Mathematical Formula

Mathematically, the heat loss in a PV module depends chiefly upon the temperature conditions and is given by the following equation:

$$Q_L = \left[\bar{h}_c . C(T_c - T_o) + \in C . \sigma . \left({T_c}^4 - {T_o}^4\right)\right] . A_c . N_c \qquad 3.9$$

Q_l= Heat loss

h_c = Thermal heat transfer coefficient

T_c = Temperature of the cell

T_o = Reference temperature

ε = Cell emissivity

σ = Stefan Boltzman constant

3.3.9.2 MATLAB Sub-System

The subsystem designed for the heat loss is as follows:

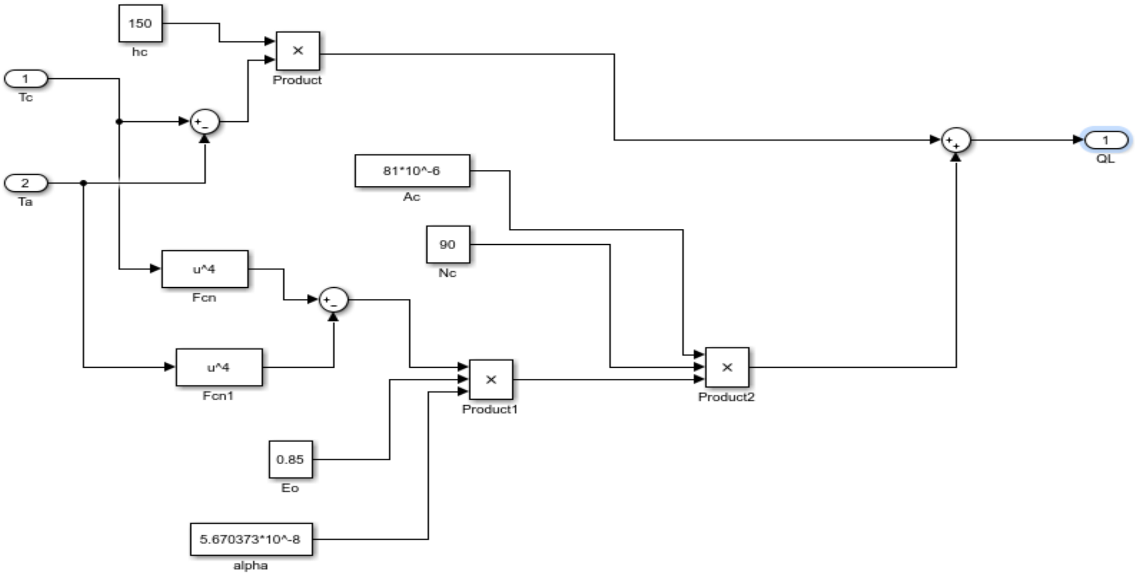


Figure 3.10: MATLAB Subsystem for Heat Loss through Radiation.

3.3.10 Variation of Thermal Energy Output

The variation of thermal output energy depends upon the temperature difference between the input and output temperature of the fluid. It is also a function of the volume of thee flowing water.

3.3.10.1 Mathematical Formula

Mathematically, it is represented as follows:

$$Q_{th,c} = \dot{m} \times C_p \times (T_{out} - T_{in}) \qquad 3.10$$

Where

$Q_{th,c}$ = Variation in thermal power

m^o= Mass of the fluid

T_{out} = Output temperature of fluid

T_{in} = Input temperature of fluid

C_p = Specific heat of the fluid

3.3.10.2 MATLAB Sub-System

The MATLAB subsystem designed is as follows:

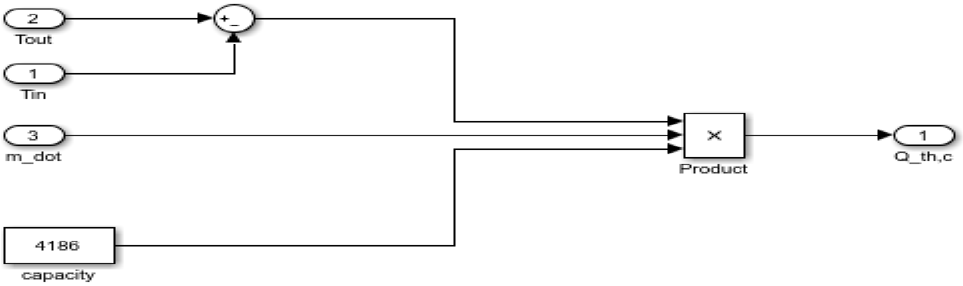


Figure 3.11: Variation of Thermal Energy Output.

3.3.11 Output Temperature

One of the output variables is the output temperature of the fluid. This temperature can be utilized in many ways. This temperature affects the efficiency of the system as well. The system has highest efficiency when the system has the optimal temperature. At very high temperature, the efficiency of the trough decreases and the same happens when the temperature is too low.

3.3.11.1 Mathematical Formula

The output temperature is the function of the input temperature and the mathematically, the output temperature is given as follows:

$$T_{out} = T_p - \left[T_p - \frac{T_{in}}{e^{\frac{h_c \times A_c}{mc}}} \right] \qquad 3.11$$

3.3.11.2 MATLAB Sub-System

The following subsystem is designed for the calculation of the output temperature of the working fluid.

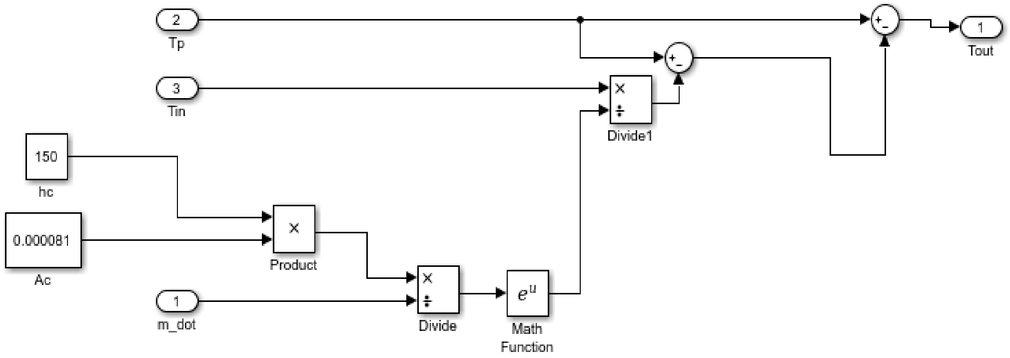


Figure 3.12: MATLAB SIMULINK Output Temperature.

3.3.12 Thermo-Electric Module (Peltier Plate)

In order to increase the net electrical efficiency of the system we are using the Thermo-Electric Module which uses the output temperature of the system and then uses it to produce electricity on the basis of temperature difference. This is completely dependent of the temperature, higher the input temperature or higher the temperature difference higher will be its efficiency.

3.3.12.1 Mathematical Formula

The Thermo-Electric Module is represented by the following formulas and it is used to calculate the output of the Module.

$$\mathbf{V} = -\mathbf{R}(\mathbf{1} - \mathbf{I}sc) \tag{3.12}$$

$$\boldsymbol{I} = \frac{[\boldsymbol{S}(\boldsymbol{Th}-\Delta\boldsymbol{T})-\boldsymbol{S}(\boldsymbol{Th}-\Delta\boldsymbol{T})^{\mathbf{2}}-\mathbf{2}\frac{\Delta\boldsymbol{T}}{\boldsymbol{Z}}]^{\mathbf{0.5}}}{\boldsymbol{R}} \tag{3.13}$$

3.3.12.2 MATLAB Sub-System

This Sub-System is designed according to the equation of the Module. It calculates the current and voltage produced and the net Power output of the System.

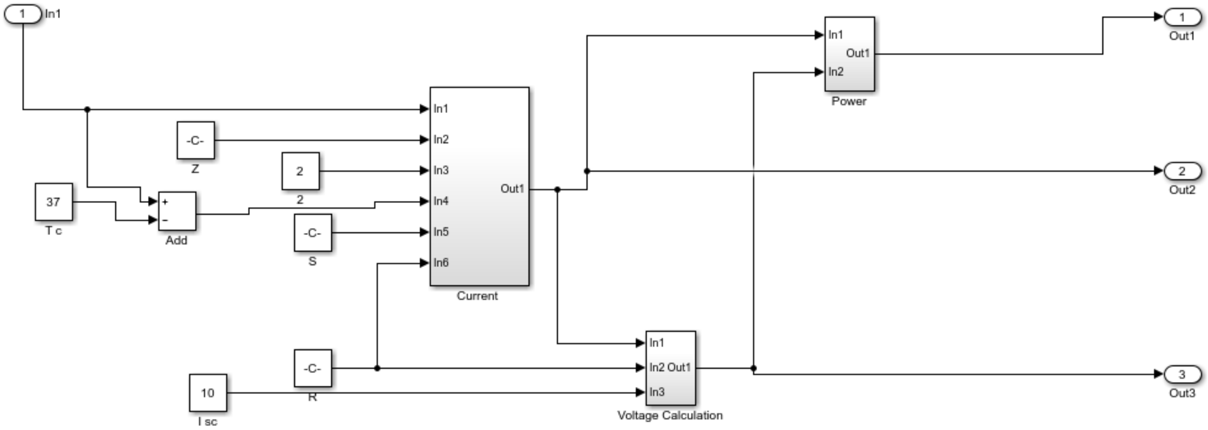


Figure 3.13: MATLAB Simulink Model of Thermo-Electric Module.

3.4 Output Measurements

The output parameters are chosen that are of maximum concern related to the electrical studies. The conventional solar concentrators are used to obtain the maximum electricity whereas in this study the optimal working conductions of the parabolic trough solar concentrators are used from which the thermal energy is also yielded which can be used to generate steam for the production of electricity, making it more efficient. The chief output parameters studied in this system are the electrical power, thermal power, overall efficiency and the temperature of the working fluid. The detail of the output parameters is described below:

3.4.1 Electrical Power

Now-a-days, the effective generation of the electrical power is main purpose of the PV system installation. The electrical power from the solar concentrator depends upon a number of factors.

Among these parameters, a variable that affects electrical output includes the concentration ratio, incident angle of solar radiation and the value of direct radiance on the parabolic trough. The model was simulated for annual span taking values on monthly basis. The values are recorded in an Excel file, so that the comparison can be made later.

Moreover, the net Electrical output of the PV system is then added with that added in the system by the thermo electric module and the combine results are used for the comparison.

3.4.2 Thermal Power

Although, the electrical power generation is main purpose of the PV system installation, but the thermal energy can also be obtained which can indirectly be used in production of electricity. The thermal power from the solar concentrator depends upon several factors. Among these parameters, the variables that affects thermal output includes the incident angle of solar radiation, the value of direct radiance on the parabolic trough temperature of the cell and input temperature of the working fluid. The model was simulated for annual span taking values on monthly basis. The values are recorded in an Excel file for the comparison.

3.4.3 Efficiency

The designed system considers both the electrical and thermal output. The efficiencies of both the energies combine to give the efficiency of the whole system. The mathematical model was simulated for annual span taking values on monthly basis. The values are recorded in an Excel file for the comparing them with the values of other variables.

3.5 Conditions to be analyzed

The various cases studied are as follows:

- Change in the Parabolic Trough (Concentration Ratio)
- Change of the Solar Irradiance
- Change of the Input Temperature
- Gain due Thermo-Electric Module

Chapter # 4: RESULTS

4.1 Introduction to MATLAB

MATLAB stands for Matrix Laboratory. It is widely used software which focuses on the simulation of the real time systems. It is user-friendly software which allows the user to flexibly work on the multiple ranges of parameters at a time. It can easily manipulate all the worldly operations which can be solved by means of matrix. MATLAB is extensively used now days because of its precise performance, high level language and the easy-to-use GUI.

It covers a wide range of subject area like calculus, algebra, engineering, stats and other mathematical manipulations. It also offers the perk of providing the solution and simulation of all soft of operations that needs pictorial description.

There are different tools for data analysis and elaboration in MATLAB which includes the

1. Statistics Tools
2. Neural Network Tools
3. Fuzzy Logic Tools
4. Image Processing Tools
5. Signal Processing Tools
6. Wavelet Tools
7. Financial Tools
8. Bioinformatics Tools
9. Database Tool and many others.

- ## Regression Analysis

There are different kinds of Regression Analysis that being used and practiced in the industrial analysis & system for curve fitting purposes.

1. Linear
2. Logarithmic
3. Powerx
4. Moving Average
5. Polynomial
6. Exponential

The Polynomial Regression analysis works well for large data sets with frequently changing values that have several rises and falls. In polynomial regression, a polynomial is grouped by the degree of the largest power or degree. The exponent of the polynomial describes the number of bends in the provided data. For example, a quadratic regression analysis has one bend, a cubical polynomial regression has 1 or 2 bends, and a quartile polynomial regression has up to 3 bends. When adding a polynomial trend line in any chart, you specify the degree by typing the corresponding number. This type of data fits a line through the equation in the form of

$$y=m0 + m1 * x + m2 * x2+ m3 * x3 +...+ m9 * x9 + \ldots\ldots\ldots\ldots..$$

We’ll be using the Polynomial Regression Analysis in simulation of our system.

4.1.1 Steps for MATLAB Regression Analysis

For the mathematical modeling, the regression analysis was chosen. The different steps participating in the polynomial regression analysis of the system parameters are detailed below;

Step 1: The first step included the identification and selection of all the concerned parameters of the CPV/T system.

Step 2: The next step involved the tabular arrangement of the factor affecting the observed model of the CPV/T system.

Step 3: In this step, the relationship between the input and output parameters is calculated

Step 4: The last step is the attaining the equations, for simple Regression and different degrees polynomials which incorporated the finest, demonstrating the correlation of the external factors and performance parameters using MATLAB.

4.2 Input Data

The different specifications and constants were implemented in the system based on the real time values. The input data selected is tabulated as follows:

Table 6: Input Data.

Parameters	**Value**
Number of cells N_C	90
Area of cells A_C	81×10^{-6} m
Type of optic	Parabolic concentrators with optical efficiency 0.85
Concentration factor C	1 : 900
Cell temperature T_C	100 Co
Trucker system efficiency f	0.9
Temperature coefficient a	-0.0016

Module Efficiency η_{mod}	0.9
Losses factor G_{par}	0.023
Inverter efficiency η_{in}	0.9
Fluid specific heat specific heat C_p	For water 4180 $JKg^{-1}K^{-1}$
Fluid input temperature T_{in}	25 C^o
Cell Emissitivity ε_C	0.85
Stefan constant	5.670373×10-8 W/m^2k^4
Convection heat transfer h_C	For water150 W/m2.Co
Conductive conductance k	For copper 384 W/m.k
Heat exchanger thickness d	2×10^{-3} m

4.3 Comparison of Output Data

Under the action of varying input variables, the readings were recorded from the simulation of the given system. These values were recorded in the spreadsheet and after all the scenarios were observed, the comparison between the parameters was made, leading to the conclusive optimal working value of the input parameters.

4.3.1 Electrical Power

The value of the concentration ratio of the parabolic trough solar concentrator and the incident angle were taken as the input variables. Series of values were taken under various input conditions and the values were compared with the fluctuating real-time values. The following conditions were analyzed for the electrical power.

4.3.1.1 For C = 500

For the concentration ratio equals to 500, the variation of the electrical power with the change in the direct solar irradiance and the incident angles was observed. Following graph shows the variation on monthly basis.

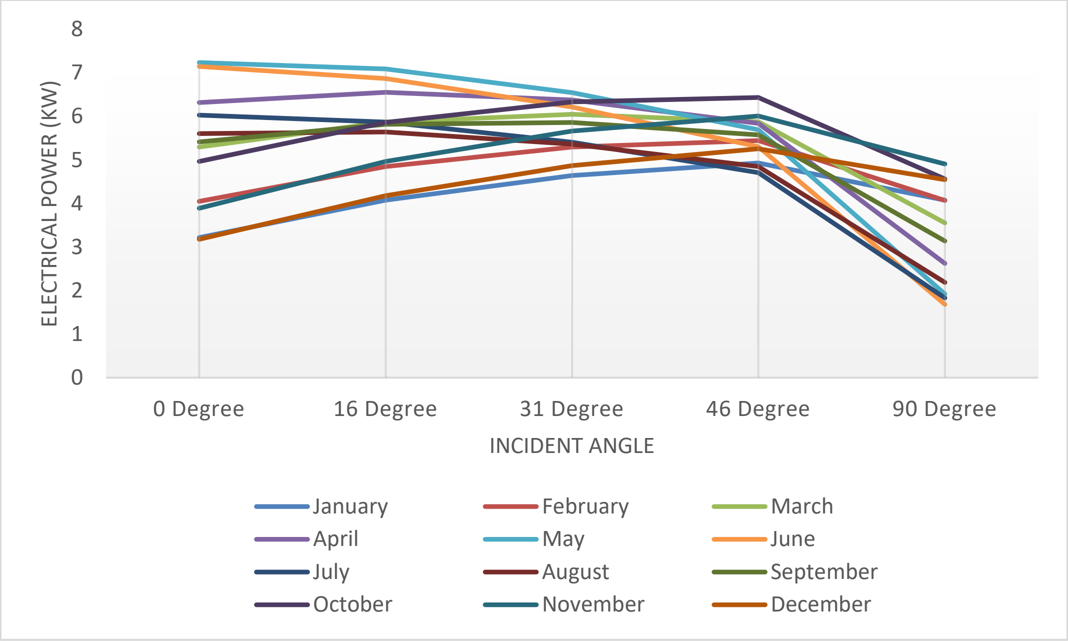


Figure 4.1: Electrical Power for C=500.

4.3.1.2 For C = 900

For the concentration ratio equals to 900, the variation of the electrical power with the change in the direct solar irradiance and the incident angles was observed. Following graph shows the variation on monthly basis.

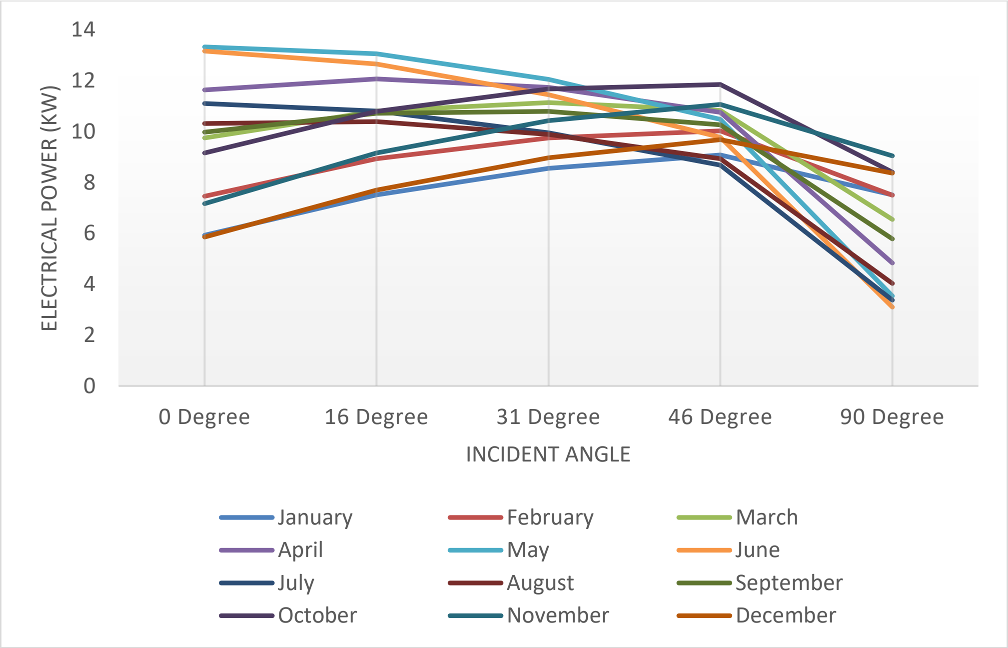


Figure 4.2: Electrical Power for C=900.

4.3.2 Thermal Power

The value of the concentration ratio of the parabolic trough solar concentrator and the incident angle were taken as the input variables. Series of values were taken under various input conditions and the values were compared with the fluctuating real-time values. The following conditions were analyzed for the thermal power.

4.3.2.1 For C = 500

For the concentration ratio equals to 500, the variation of the thermal power with the change in the direct solar irradiance and the incident angles was observed. Following graph shows the variation on monthly basis.

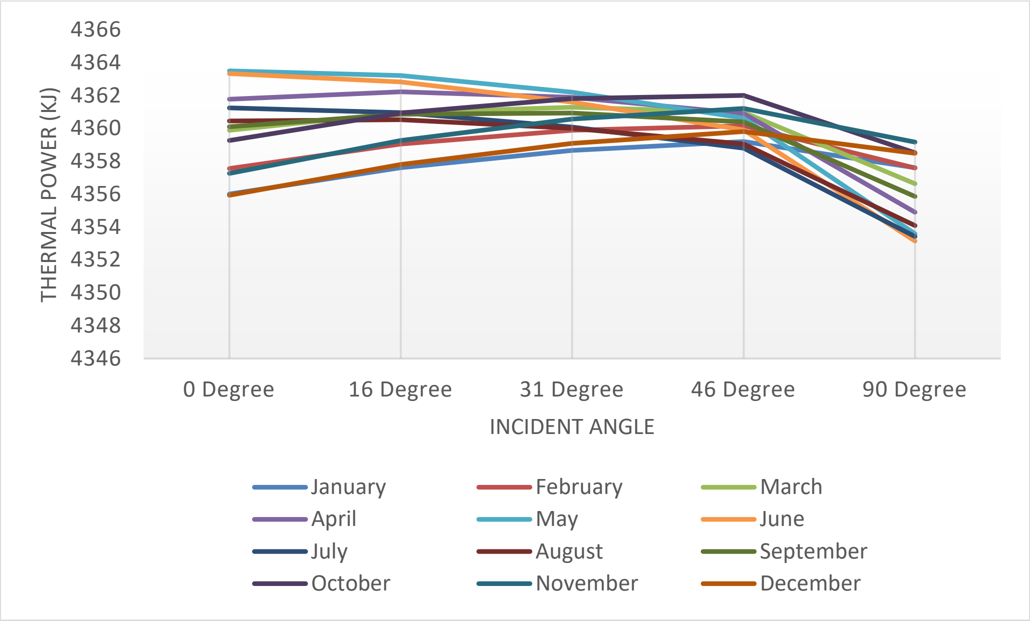


Figure 4.3: Thermal Power for C=500.

4.3.2.2 For C = 900

For the concentration ratio equals to 900, the variation of the thermal power with the change in the direct solar irradiance and the incident angles was observed. Following graph shows the variation on monthly basis.

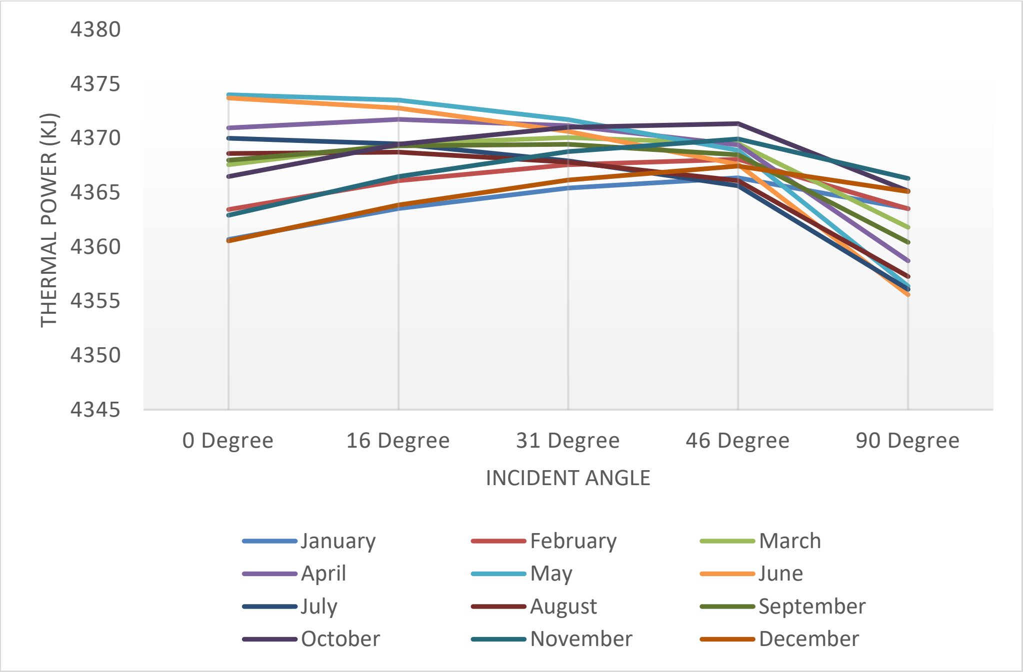


Figure 4.4: Thermal Power for C=900.

4.3.3 Overall Efficiency

The value of the concentration ratio of the parabolic trough solar concentrator and the incident angle were taken as the input variables. Series of values were taken under various input conditions and the values were compared with the fluctuating real-time values. The following conditions were analyzed for the overall efficiency of the system.

4.1.3.1 For C = 500

For the concentration ratio equals to 500, the variation of the overall efficiency with the change in the direct solar irradiance and the incident angles was observed. Following graph shows the variation on monthly basis.

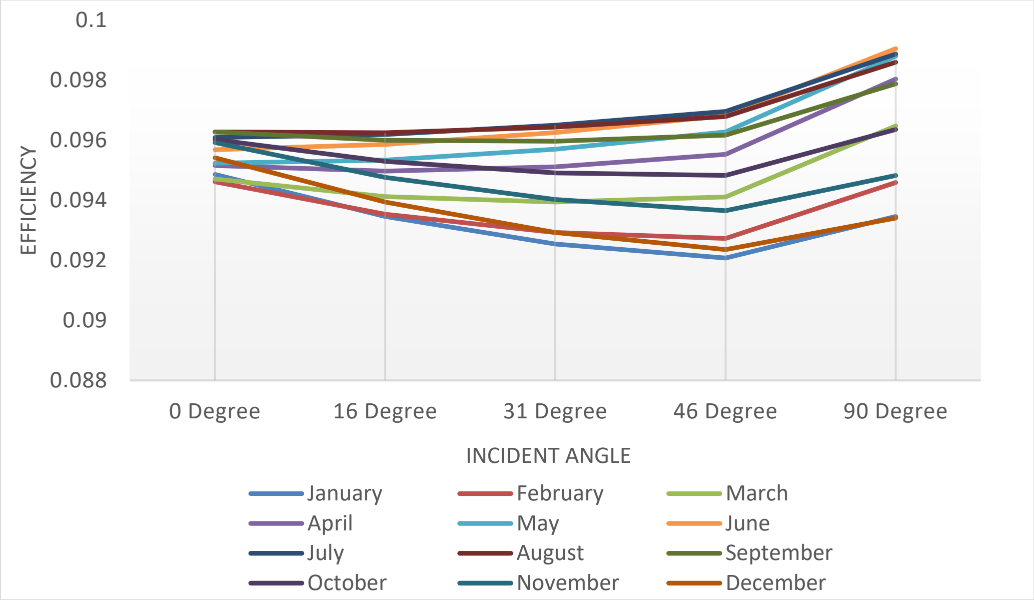


Figure 4.5: Efficiency for C=500.

4.3.3.2 For C = 900

For the concentration ratio equals to 900, the variation of the overall efficiency with the incident angles was observed. Following graph shows the variation on monthly basis.

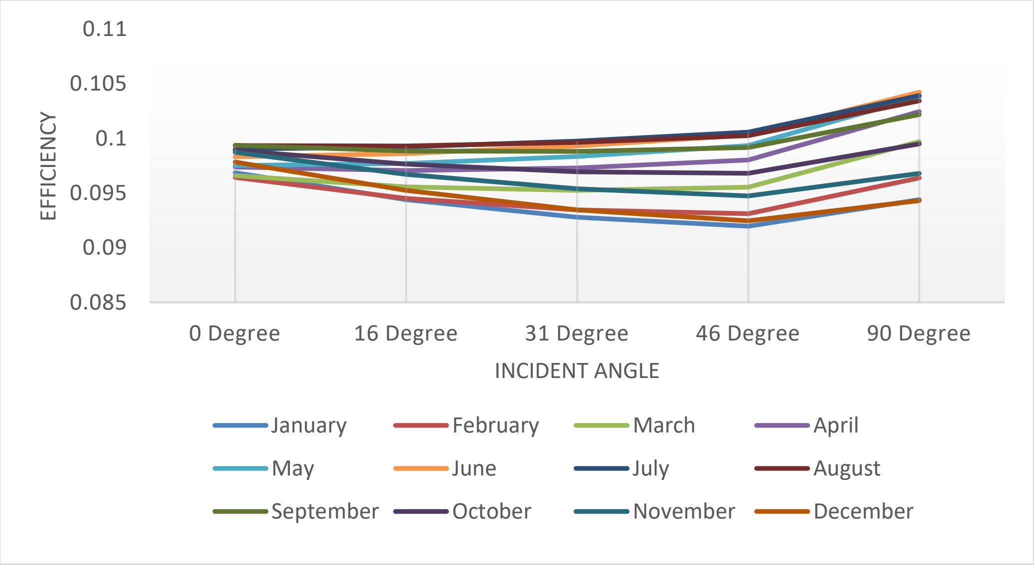


Figure 4.6: Thermal Power for C=900.

4.4 Effect of Concentration Ratio on Other Factors

The concentration ratio affects the output yield of the parabolic trough parameters in many ways. The effect of concentration ratio on the concerned output parameters i.e. the electrical power, thermal power and the overall efficiency of the solar concentrator is given below:

4.4.1 Electrical Power

The more the value of the concentration ratio, the more solar radiations will be captured by the photovoltaic material and the more will be the electrical power. The following graph shows the impact of concentration ratio on the electrical power for each of the month.

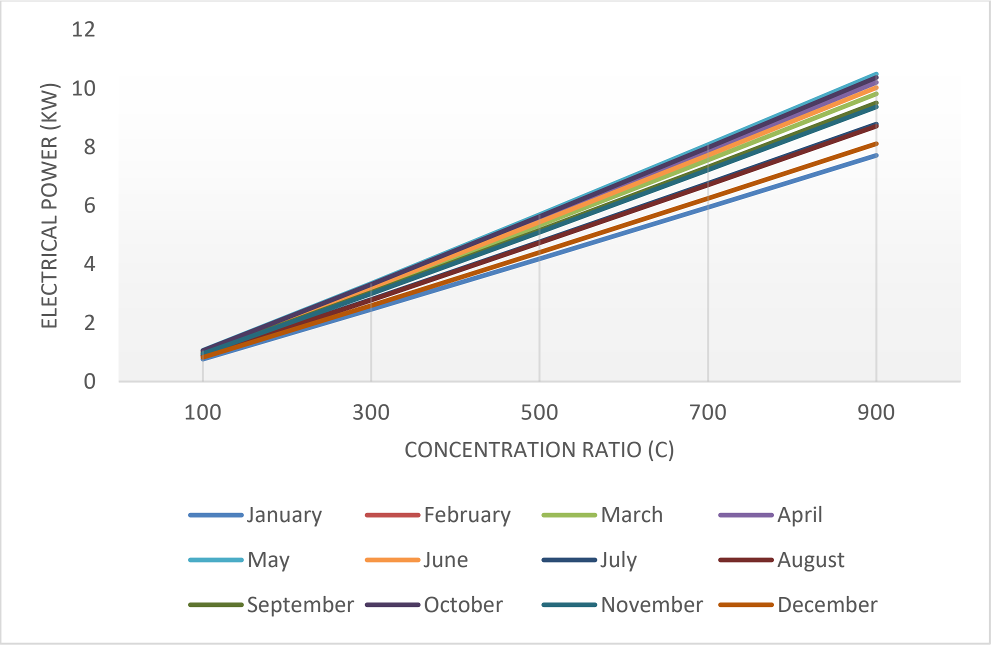


Figure 4.7: Effect of C on Electrical Power.

4.4.2 Thermal Power

The more the value of the concentration ratio, the more solar radiations will be captured by the photovoltaic material and the more will be the electrical power. The following graph shows the impact of concentration ratio on the electrical power for each of the month.

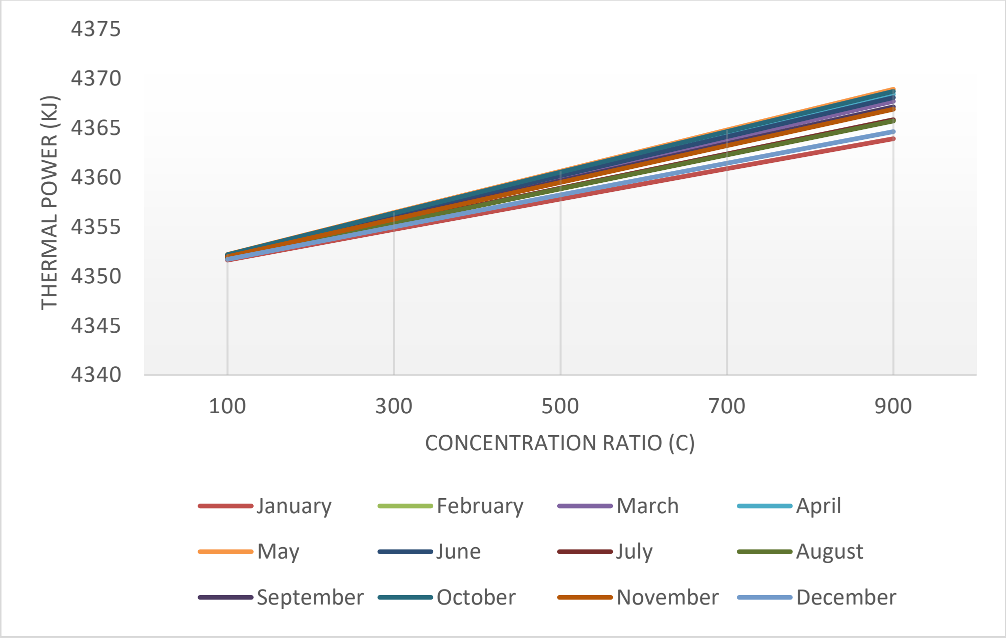


Figure 4.8: Effect of C on Thermal Power.

4.4.3 Efficiency

The more the value of the concentration ratio, the more solar radiations will be captured by the photovoltaic material and the more will be the electrical power as well as the thermal power. Thus, more will be the efficiency of the studied system. The following graph shows the impact of concentration ratio on the electrical power for each of the month.

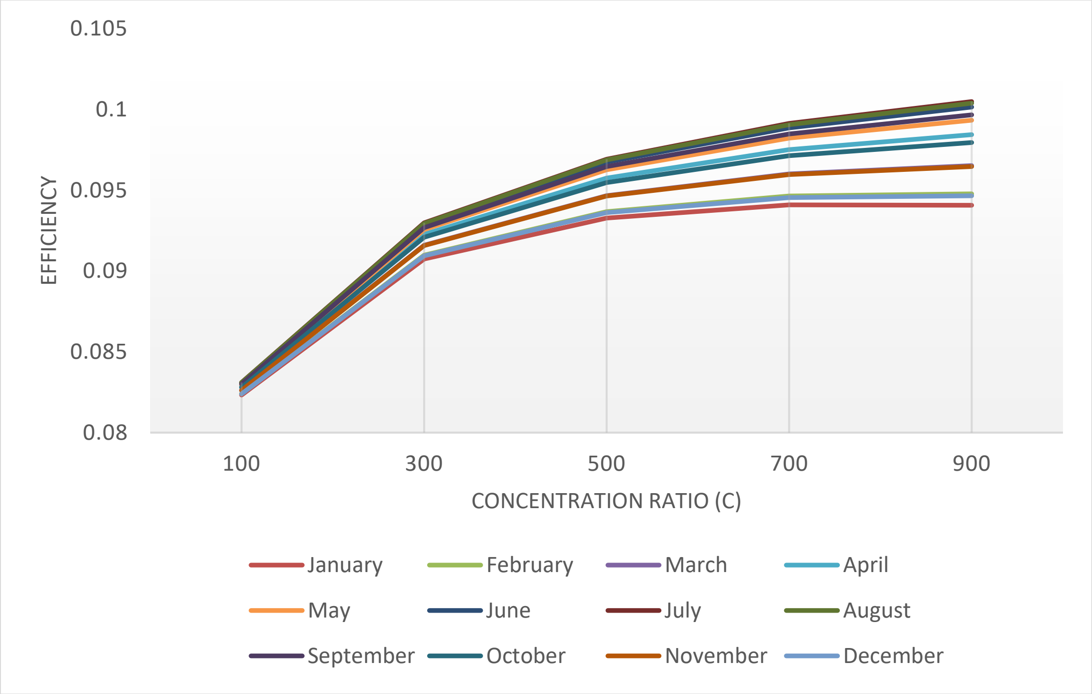


Figure 4.9: Effect of C on Efficiency.

4.5 Effect of Thermo-Electric Module on the Output

The Electrical Efficiency of the System increased as we used the thermo electric module i.e Peltier Plate. The Peltier Plate is directly dependent on the input temperature. The greater the difference would be between the input temperature and the atmospheric temperature the Output will increase proportionally.

The net Electrical Power of the System increases at least 4 to 5 times than without the Thermo Electric Module.

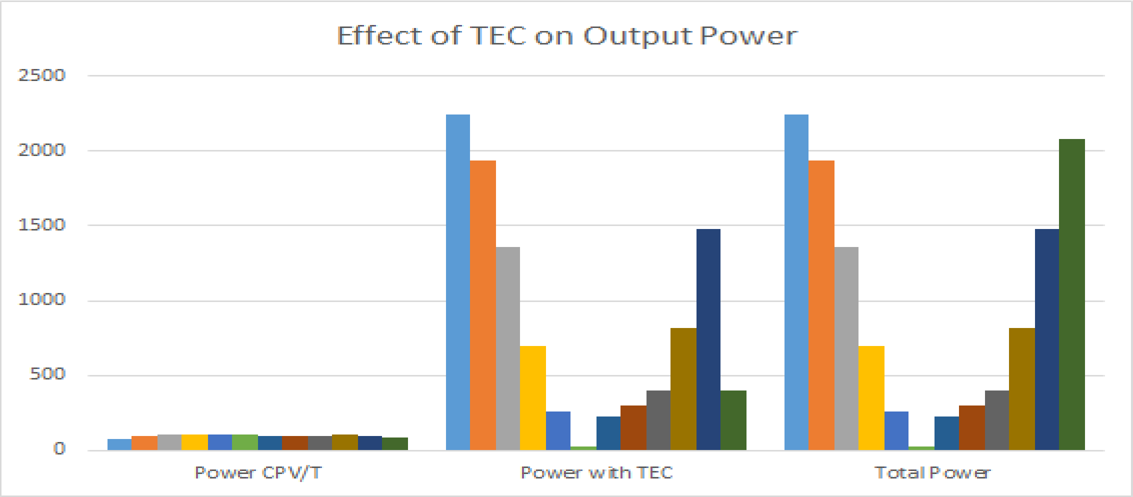


Figure 4.10: Effect of Thermo-Electric Module on the Output Electric Power.

4.6 Selection of Optimal Incident Angle

The selection of the optimal incident angle is a major task in obtaining the maximum yield in terms of the electrical and thermal power of the parabolic trough solar concentrator. The analysis of the graphs in the section 4.1 shows that the maximum power is available when the sun rays fall the system at an angle of 45 degrees. After a certain value of thermal energy, the efficiency starts to decrease showing that temperature exceeds. So, the results show that the optimal incident angle of the solar radiation is 45^o with the normal of the parabolic trough.

Chapter # 5: Conclusion

The parabolic trough solar concentrators are used to concentrate the solar radiations on the photovoltaic material which maximizes its efficiency. The mathematical modeling of the system is simulated to analyze the dependence of the input parameters on the output electrical and thermal power. The effect of two parameters was discussed for the proposed system including the optimal angle for the working of the parabolic trough. The graphs obtained by the simulation shows that the electrical and thermal power is maximum at 45 degree and then keeps on declining while the efficiency of the system is increasing till 45 degrees then it further increases till the maximum 90 degrees. The efficiency is inversely proportional to the heat produced after a certain limit. After 45 degrees, the heat energy is reduced which results in the increase of efficiency. Thus, the optimal working angle of the incident sun rays for the parabolic concentrators is 45 degree at which the electrical power, thermal power and the collective efficiency is optimized.

The Concentration ratio is defined as the ratio of the concentrator aperture area to the receiver aperture area (for a specific PV material). The simulation shows that the greater the value of C, greater will be the Power as well as the efficiencies. The more area provided for the radiation, the more reflection and utilization of solar energy is possible. The value of the concentration ratio is directly proportional to both the electric as well as thermal output.

The addition of Thermo-Electric Module with this system significantly increased the net Electric Power of the System. This not only made the system more productive but at the same time more efficient. Maximum amount of energy is being harvested by a single system with minimum losses.

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