Designing CPV panel and it's Cooling system

A BS Final Year Project by

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Certificate of Approval

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بسم الله الرحمن الرحيم

In the name of Allah (SWT), the most beneficent and the most merciful

A BS Final Year Project submitted to the

Department of Electrical and Computer Engineering

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In partial fulfillment of the requirements

For the award of the degree of

Bachelor of Science in Electrical Engineering

Declaration

We hereby declare that this work, neither as a whole nor as a part thereof has been copied out from any source. No portion of the work presented in this report has been submitted in support of any application for any other degree or qualification of this or any other university or institute of learning. We further declare that the referred text is properly cited in the references.

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Date Started: September, 2022

Date Completed: May, 2023

Tools Used:

- Silicon solar cells 0.7V
- Reflector Mirrors
- PV ribbons
- Hard Plastic Base
- DC motor
- Water Pump
- Stand

 DMM

Abstract

In modern days ,the biggest issue the mankind is facing is climate change.Energy production contributes a lot in it. Humans are trying to enhance the conventional methods of production of electricity by switching to renewable energy sources.They are more eco-friendly and cheaper. The solar energy is widely used in generating power on industrial as well as commercial level. Our projects relate to a category of methods to generate electricity by using concentrated sunlight.

Table of Contents

List of Figures

List of Abbreviations

CPV	Concentrated Photo-voltaic
FYDP	Final Year Design Project
PV	Photovoltaic
LDR	Light Dependent Resistor
LCD	Liquid Crystal Display
PCRET	Pakistan Council of Renewable Energy Technology

Chapter 1
Introduction

We have designed a cost effective CPV panel and an efficient cooling system to solve its overheating problem. The CPV panel is constructed using medium concentration technology.For that purpose, reflectors will be added to each cell which will concentrate sunlight hitting the panel. In this way the CPV panel gives up-to 46 % of efficiency while the normal solar panels of the same size give the efficiency of just up-to 22%.

More light concentration comes with its own complications like it heats the panel on a bright sunny day. This problem is solved by the tube cooling method. In this method a container filled with water is attached behind the panel and a tube extending in the bottom of the panel is attached to a radiator that will cool down the water and a pump will carry that cooled water back into the container. To check the working of the panel, a voltmeter is connected to the output which displays the produced voltage on the LCD.

• Motivation

The main motivation was when we started our summer internship in Pakistan Council of Renewable Energy Technology PCRET. We worked as interne engineers in Lamination Lab and learned about solar panel manufacturing. We also learned the manufacturing process of a solar cell and its working. At the end of our internship we were motivated for this final year project and we decided to build a panel which is more efficient and gives better performance than an ordinary solar panel available in the market.

• Project Overview

The concentrated photovoltaic (CPV) panel project aims to develop and deploy an innovative solar energy solution that maximizes the efficiency and output of photovoltaic systems. By harnessing concentrated sunlight, this technique offers a better conversion rate of solar energy into electricity, making it a possible alternative to standard solar panels. This project overview includes a full summary of the objectives, technique, and potential benefits of adopting concentrated photovoltaic panels.

Our project contains two strings, each string consist of 3 solar cells. These cells are surrounded by reflector mirrors that concentrates the Sunlight at each cell. More concentration will result in more power at the output. But that will also produce more heat that can damage the solar cell. To overcome this heating problem we have also designed a cooling system. cooling system consist of two containers filled with water which will circulate under the panel to protect it from overheating.

• Problem Statement

The topic at hand revolves on the limitations and challenges associated with standard solar panels, which have led to the necessity for a novel solution in the shape of concentrated photovoltaic (CPV) panels. The problem statement can be defined as follows:

- **Low Efficiency:** Traditional solar panels have weak energy conversion efficiency, resulting in inadequate electricity output. The challenge resides in their inability to properly catch and convert a considerable percentage of the available sunlight into useful electricity. This inefficiency hampers the possibility of solar energy as a viable alternative to conventional power sources.

- **High Cost:** Another difficulty with typical solar panels is their relatively high cost, which limits their widespread adoption and hinders their economic sustainability. The manufacturing techniques, materials, and technologies utilised in the creation of these panels contribute to their high price point, rendering them inaccessible to a wider percentage of the population and limiting the pace of solar energy deployment.

- **room Requirements:** Traditional solar panels require a great amount of room to create a significant amount of electricity. The enormous area needed for their installation causes issues in urban contexts where space is scarce or expensive. Furthermore, this criterion inhibits the deployment of solar energy in locations with restricted land availability, so restricting the reach and potential impact of solar power.

- **Environmental Impact:** While solar energy is commonly acknowledged as a clean and sustainable energy source, typical solar panels nevertheless have certain environmental problems. The production process involves the use of materials that may have severe environmental impacts, including the mining and disposal of rare earth minerals. Additionally, the low energy conversion efficiency of solar panels implies a larger number of panels are required, resulting to a higher carbon footprint in the production and transportation operations.

- **Thermal Management:** Traditional solar panels are subject to overheating, especially in places with high ambient temperatures. This extra heat decreases the panels' efficiency and can lead to performance degradation and shortened lifespan. Effective thermal management solutions are essential to solve this issue and ensure optimal performance and durability of solar panels.

• Project Objectives

The key aims of the CPV panel project are as follows:

- **Efficiency Enhancement:** The project intends to build a CPV system that can greatly boost the efficiency of solar energy conversion, resulting in a higher electricity output compared to ordinary solar panels. This purpose entails optimizing the design of concentrates, solar cells, and cooling methods.

- **Cost Reduction:** Another major goal is to discover ways to reduce the overall cost of concentrated solar panels, making them more economically viable for wider deployment. This comprises optimizing production processes, decreasing material prices, and strengthening the system's resilience and lifetime.

- **Environmental Sustainability:** The CPV panel project strives to promote clean and sustainable energy generation by utilizing solar electricity. By producing efficient and cost-effective CPV panels, the initiative intends to contribute to the reduction of greenhouse gas emissions and battle climate change.

Mainly the objective of our project was to design a Solar Panel that produce clean energy and gives the efficiency of about 45%. An other objective of our project was to design a cooling system for that panel.

• Brief Project Methodology

The project will involve the following essential steps:

- **Research and Development:** Extensive research will be performed to examine existing CPV technologies, identify potential enhancements, and investigate new materials and manufacturing procedures. This phase will also involve testing and evaluating different concentrator designs, solar cell technologies, and cooling systems.

- **Prototype Development:** Based on the research findings, a prototype CPV panel system will be built, including the optimized concentrates, high-efficiency solar cells, and an effective cooling mechanism. This prototype will be thoroughly tested in laboratory and field circumstances to certify its performance and efficiency.

- **Performance Optimization:** The feedback and data received from prototype testing will be used to modify and optimize the CPV system. This iterative process may involve design revisions, efficiency increases, and further testing to achieve maximum performance and dependability.

- **Scaling and Commercialization:** Once the CPV panel system has been refined and demonstrated to be feasible, efforts will focus on scaling up production and commercialization. Manufacturing procedures will be streamlined, production costs will be optimized, and distribution channels will be built to get the CPV panels to the market.

The CPV project uses concentration methodology in which it concentrates sun light to increase the efficiency of solar panel. Raw solar cells are used in the project. Reflector mirrors concentrate light on each cell on the panel. Light source is Sun and photons present in sunlight.

Each cell is connected by PV ribbons that carry charge. Cells are connected in series and the output is taken by two terminals. A junction box is used for output terminals. Cells are being protected by Tempered glass from upper surface and by Fiber glass from bottom surface.

Cooling system consist of two containers filled with water. Water is pumped by a pump to keep the temperature controlled and protect cells from overheating.

Chapter 2
Literature Review

- **Concentration photovoltaic (CPV)** is a photovoltaic technique that generates power from sunshine. Unlike traditional photovoltaic systems, it uses lenses or curved mirrors to focus sunlight onto small, extremely efficient, multi-junction (MJ) solar cells.

1.Classifications: The PV cells are separated into 3 classifications:

•Low concentration

•Medium concentration

•High concentration

2.Methods of Concentration:

There are 3 methods of concentration of light into the PV cells, these are:

•Fresnel lens

•parabolic mirrors

•Reflectors

2.1.Fresnel lens:

It comprises portions with varied angles furthermore it reduces weight and thickness of lens compared to a conventional lens.

•2.2.Parabolic Mirrors:

These are the curved mirrors that converge the light into a narrow surface. When the light beam meets the the curved surface it deflects back where a small layer is present that collects that converged light beams thereby reducing loss.

2.3.Reflectors:

In this approach two reflectors are put on the opposite ends of a solar cell in such an angle that when a light beam reaches the reflectors, it bounces straight on the solar cell.

3. **Material utilized in CPV:**

There are both Lower and higher efficiency materials used in CPV technology like

Silicon

Cadmium telluride

Copper indium Gallium selenide cells

Here we are dealing with silicon because it's the cheapest and most abundant semiconductor available.

4.Best locations to place CPV:

The CPV can only employ direct beam radiation and cannot use diffuse radiation. For this purpose :

They should be employed in the areas with high normal irradiance.

For proper light concentration, sun tracking is needed to achieve high cell performance

- ## .Background of Project:

Solar energy is a promising renewable energy source that has attracted substantial attention in recent years due to its potential to ameliorate climate change and reduce dependence on fossil fuels. Photovoltaic (PV) technology, which transforms sunlight directly into electricity, has been widely used as a technique of harvesting solar energy. However, standard PV panels have certain limits in terms of efficiency, cost, space requirements, and environmental impact.

Efficiency Limitations: Traditional PV panels have a rather low energy conversion efficiency, often ranging from 15% to 20%. This means that a considerable part of the sunlight that reaches the panels is not transformed into usable electricity. This inefficiency lowers the total productivity of solar energy systems and demands bigger surface areas for installation to generate a desired amount of electricity.

Cost Challenges: The cost of standard PV panels, mostly driven by production methods and material expenditures, has been a barrier to their wider adoption. Although the cost of PV systems has greatly fallen over the years, it still represents a major investment, especially for bigger installations. The high upfront costs and extended payback periods have impeded the mainstream use of solar energy in many regions.

area Requirements: Traditional PV panels require extensive land or roof area to generate significant electricity generation. This requirement might be an issue in metropolitan locations, where space is limited and expensive. Additionally, the necessity for massive solar farms or large rooftop installations might be restricted in places with limited land availability or severe zoning rules. These issues limit the scalability and accessibility of solar energy systems.

Environmental problems: While solar energy is acknowledged as a clean and sustainable energy source, typical PV panels still have significant environmental problems. The manufacturing process requires the usage of resources like as silicon, which require energy-intensive extraction and processing procedures. Furthermore, the disposal of PV panels at the end of their lives raises concerns about effective recycling and waste management techniques. Additionally, the low efficiency of typical PV panels needs a higher number of panels to reach a specified energy output, resulting in a bigger carbon footprint associated with manufacture and transportation.

To solve these restrictions, concentrated photovoltaic (CPV) panels have developed as an innovative option. CPV technology utilizes optical concentrators to focus sunlight onto small, high-efficiency solar cells, enabling a higher conversion of solar energy into electricity. By focusing the sunlight, CPV panels can achieve much better energy conversion efficiency compared to standard PV panels. This enhanced efficiency allows for the generation of more power utilizing a smaller surface area, making CPV panels appropriate for installations with restricted space availability.

Furthermore, the use of concentrates in CPV systems offers possible economic advantages. With fewer solar cells required, the manufacturing costs associated with CPV panels can be decreased. Additionally, the use of concentrates enables the use of lower-cost, high-efficiency multi-junction solar cells, which are normally more expensive and complex to manufacture for regular PV panels.

Related Work/Projects:

1. **Semprius CPV Modules:** Semprius produces CPV modules based on micro-transfer printing technology designed to deliver great performance, good reliability, and cheap cost with scalability to high-volume production. The company’s technology has other applications in flat-panel displays, electronics, large-area sensors, and radio frequency (RF) devices.

2. Amonix CPV Systems: Concentrated photovoltaic technology systems which require no water in power generation and produce more energy per acre than any other solar technology. CPV technology uses optics to focus huge volumes of sunlight onto small photovoltaic surfaces to generate power.

3. Trough Systems: Trough systems use massive, U-shaped (parabolic) reflectors that contain oil-filled pipes running at their center, or focal point

4.Power tower systems: Also called central receivers, employ multiple big, flat heliostats (mirrors) to follow the sun and focus its beams onto a receiver. As depicted in Figure 3, the receiver rests on top of a tall tower in which focused sunlight heats a fluid, such as molten salt, as hot as 1,050°F. The hot fluid can be utilized immediately to produce steam for energy generation or stored for later use. Molten salt maintains heat efficiently, thus it can be held for days before being transformed into electricity. That implies electricity can be produced during moments of high need on overcast days or even several hours after sunset.

5. Dish/engine systems: Use mirrored dishes (approximately 10 times larger than a backyard satellite dish) to focus and concentrate sunlight onto a receiver. As shown in Figure 5, the receiver is positioned at the focal point of the dish. To capture the most amount of solar energy, the dish assembly tracks the sun across the sky. The receiver is integrated into a high-efficiency "external" combustion engine. The engine includes thin tubes containing hydrogen or helium gas that run along the outside of the engine's four piston cylinders and open into the cylinders. As concentrated sunlight falls on the receiver, it heats the gas in the tubes to very high temperatures, which causes heated gas to expand inside the cylinders. The expanding gas drives the pistons. The pistons turn a crankshaft, which drives an electric generator. The receiver, engine, and generator comprise a single, integrated component positioned in the focus of the mirrored dish

Project Contribution

The project was undertaken by both of group members equally according to their expertise. During the project both members contributed equally and helped each other. Both designed the hardware of the project by mutual contribution and hard-work and also contributed equally in purchasing cells, motors, pump and other equipment like voltmeter, soldering iron and glue gun etc.

• Summary :

Concentrated photovoltaic (CPV) panels are an innovative way to address the limitations of regular photovoltaic (PV) panels. While PV technology has been widely used for solar energy generation, CPV panels offer higher energy conversion efficiencies, decreased prices, optimal land management, and improved environmental sustainability.

Traditional PV panels suffer from relatively low energy conversion efficiency, resulting in unsatisfactory electricity output. CPV panels bypass this problem by deploying optical concentrators to focus sunlight onto small, high-efficiency solar cells. This concentration of sunlight considerably boosts the energy conversion rates, leading to larger electrical outputs per unit of sunlight.

In addition to higher efficiency, CPV panels offer possible economic advantages. With fewer solar cells required, the manufacturing costs associated with CPV panels can be decreased. Furthermore, the use of lower-cost, high-efficiency multi-junction solar cells becomes viable with the use of concentrators, boosting cost-effectiveness and affordability.

Space limitations offer a difficulty for standard PV installations, especially in metropolitan areas or regions with limited land availability. CPV panels overcome this difficulty by permitting the generation of more electricity utilizing a smaller surface area. The concentration of sunlight enables for small installations, making CPV panels suited for situations where space is limited.

Environmental considerations are also addressed with CPV panels. Although standard PV panels are considered clean and renewable, the production and disposal processes present environmental problems. CPV panels lower the environmental effect by optimizing material utilisation and reducing the carbon footprint associated with manufacture and shipping.

In summary, CPV panels offer considerable gains over regular PV panels, including increased energy conversion efficiency, decreased prices, optimized land management, and improved environmental sustainability. By utilizing concentrated sunlight, CPV technology shows potential for boosting the viability and scalability of solar energy systems, leading to a cleaner and more accessible renewable energy future.

Chapter 3
System Design and Implementation

The system design and implementation consists of following steps:

- ## System Design

The CPV project uses concentration methodology in which it concentrates sun light to increase the efficiency of solar panel. Raw solar cells are used in the project. Reflector mirrors concentrate light on each cell on the panel. Light source is Sun and photons present in sunlight. Each cell is connected by PV ribbons that carry charge. Cells are connected in series and the output is taken by two terminals. A junction box is used for output terminals. Cells are being protected by Tempered glass from upper surface and by Fiber glass from bottom surface. Cooling system consist of two containers filled with water. Water is pumped by a pump to keep the temperature controlled and protect cells from overheating.

The dimensions of each cell are 6*6 inches. Length of the panel is 22 inches while its width is about 24 inches or 2 feet. Water containers are placed exactly under the position of cells to protect them from overheating. A 12 volt dc pump is used to circulate the water in both the containers.

- ## System Architecture/Flow Diagram

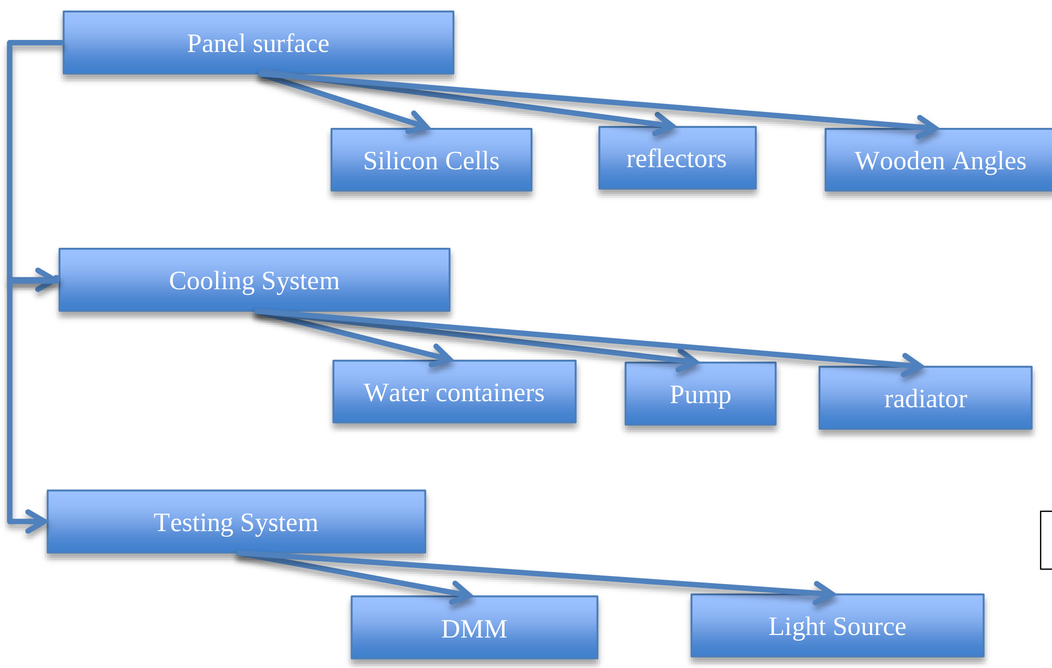

Fig 1

• Requirements/Requirements Analysis:

The basic requirements for this project are as follows:

1: Silicon cells of voltage 0.7V 6x

2: Reflector mirrors 6 sq inches 12x

3: PV ribbons

4: Plastic Base

5: Water Containers

6: Water Pump

7: Radiator

8: Tampered Glass

• Methodological/Implementation/Experimental Details

The basic purpose of introducing a CPV was to get more efficiency from a solar panel. CPV can give more than double the power of a normal Solar power. During the construction of CPV we noticed that the efficiency increased up-to 140%.

For the experiment on 21st March the voltage measured for one string should be equal to 1.2 volts but after using reflectors the cell were giving the voltage of 1.73 volts at 4:42 pm.

• Hardware/Development Setup

First of all we tabbed the cells and made 2 strings of 3 cells each.Then we made the hard plastic base and placed the strings on it. We connected the reflectors on certain angles to increase the concentration of light. We designed the cooling system using water containers and tubes. The pump is used to regulate water and radiator is used to cool it down. The DMM will be used to measure the resulting voltage.

- **Model Diagram:**

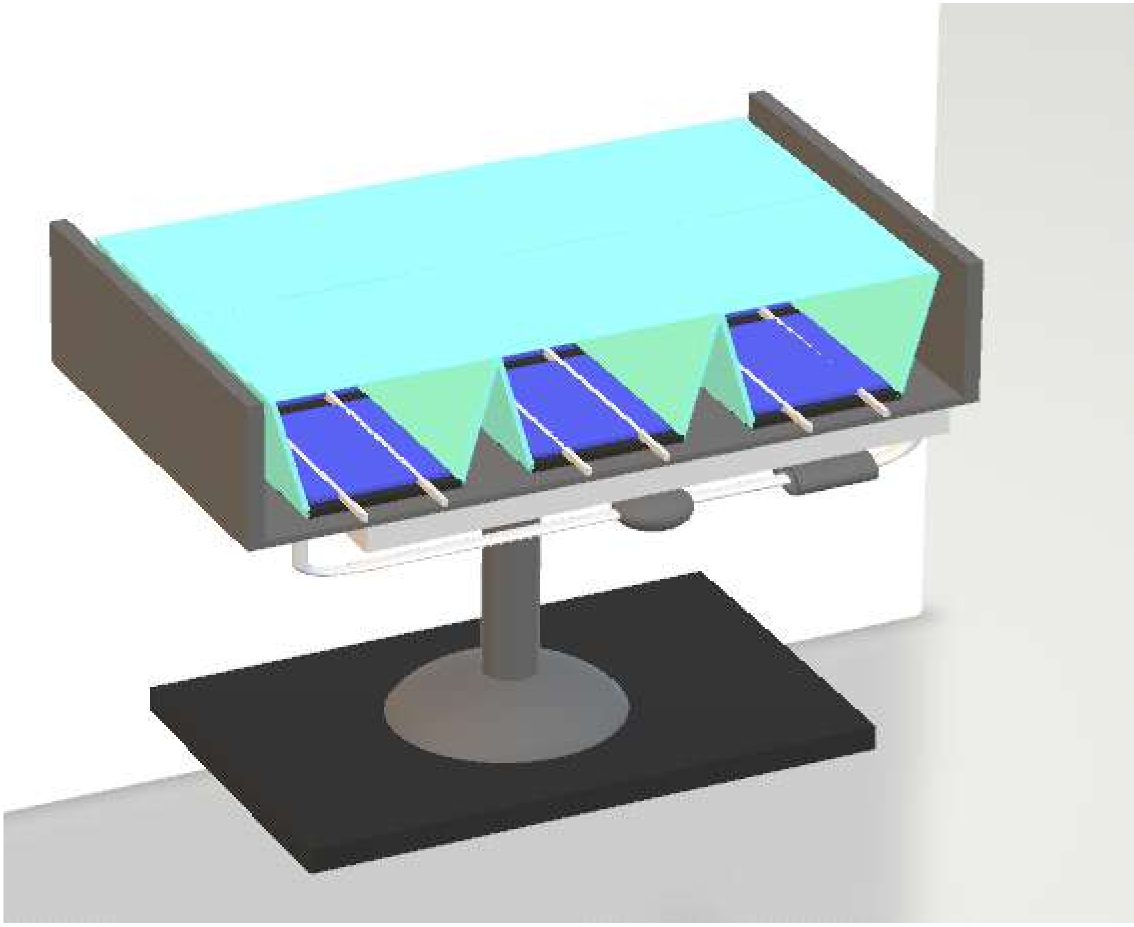

Fig:2

- **Hardware Details:**

Silicon Cell

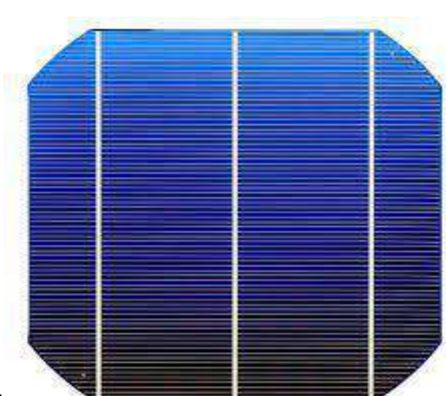

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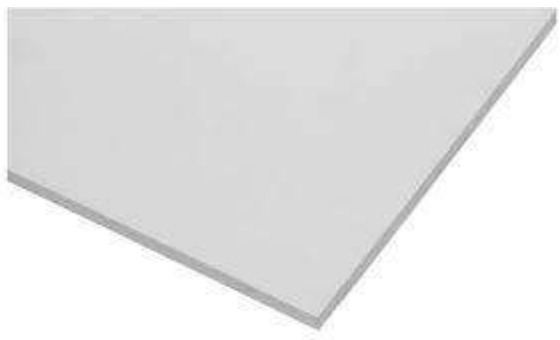
Fig 3

Reflector Mirror: fig 4

Water Pump: fig 5

Battery: fig 6

Hard Plastic:fig 7



- ## Equations Used:

Solar panel efficiency formula:

$$\text{Efficiency (\%)} = (\text{Pmax} \div \text{Area}) \div (1000) \times 100\%$$

Where Pmax is the solar panel peak power in watts and Area is the length multiplied by the width of the solar panel in square meters.

The elevation angle:

The elevation angle can be calculated from the following equation

$$\alpha = \sin^{-1} (\cos \varphi \cos \delta \cos \omega + \sin \varphi \sin \delta)$$

where the hour angle is given by $\omega = 15° (12 - TS)$; here, TS is the solar time. The geographical location parameters include the latitude angle (φ), the declination angle (δ), the hour angle (ω), and the solar altitude angle (α). The latter is also known as the elevation angle, and it refers to the angle between an imaginary line in the middle of the sun in the sky and the horizontal.

Chapter 4
Testing and Validation/Discussion

The testing process includes the testing of a CPV panel compared to the normal solar panel of same cell amount. It was proved that the normal solar panel gives the efficiency of 18 to 22%.

While a typical CPV panel gave the efficiency of almost 40%. When the normal solar panel gives the output of 2.4 Volts with 6 cells the CPV gives up-to 3.5 volts.

- ## Testing:

The testing is performed in sunlight and the voltage is measured across the strings to check if they are giving required readings.

- ## Prototypes:

The prototype consists of a 22 inch wide and 20 inch long panel which has 2 strings of silicon cells containing 3 cells each. On the back of panel surface two water containers are connected that are circulating water within thus maintaining the temperature. The panel is attached to a tilt-able stand so it can be tilted in any direction.

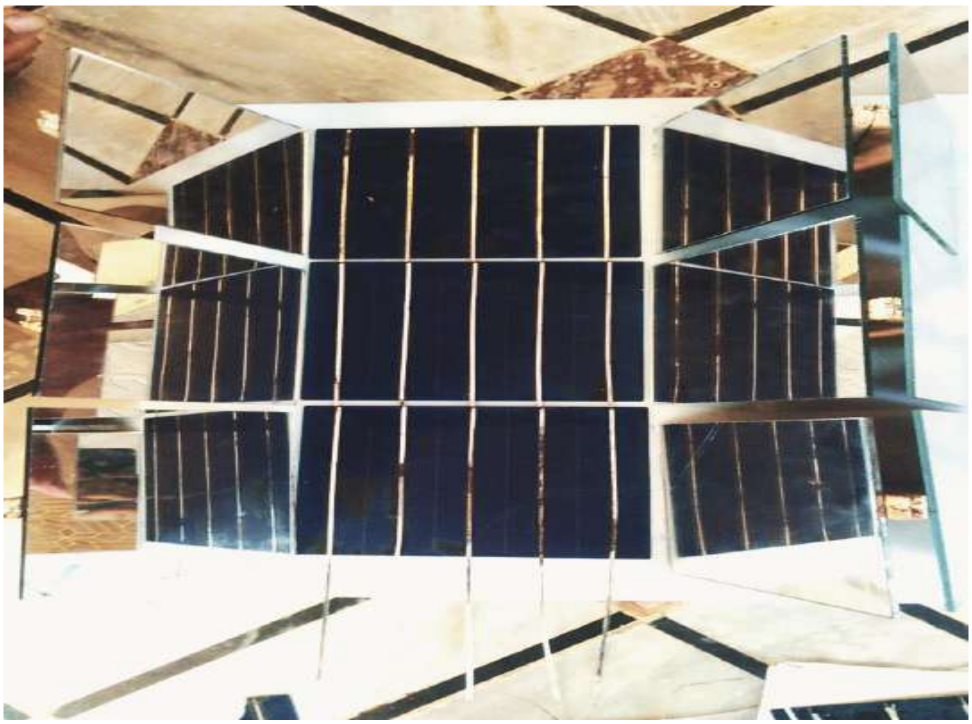


Fig 8

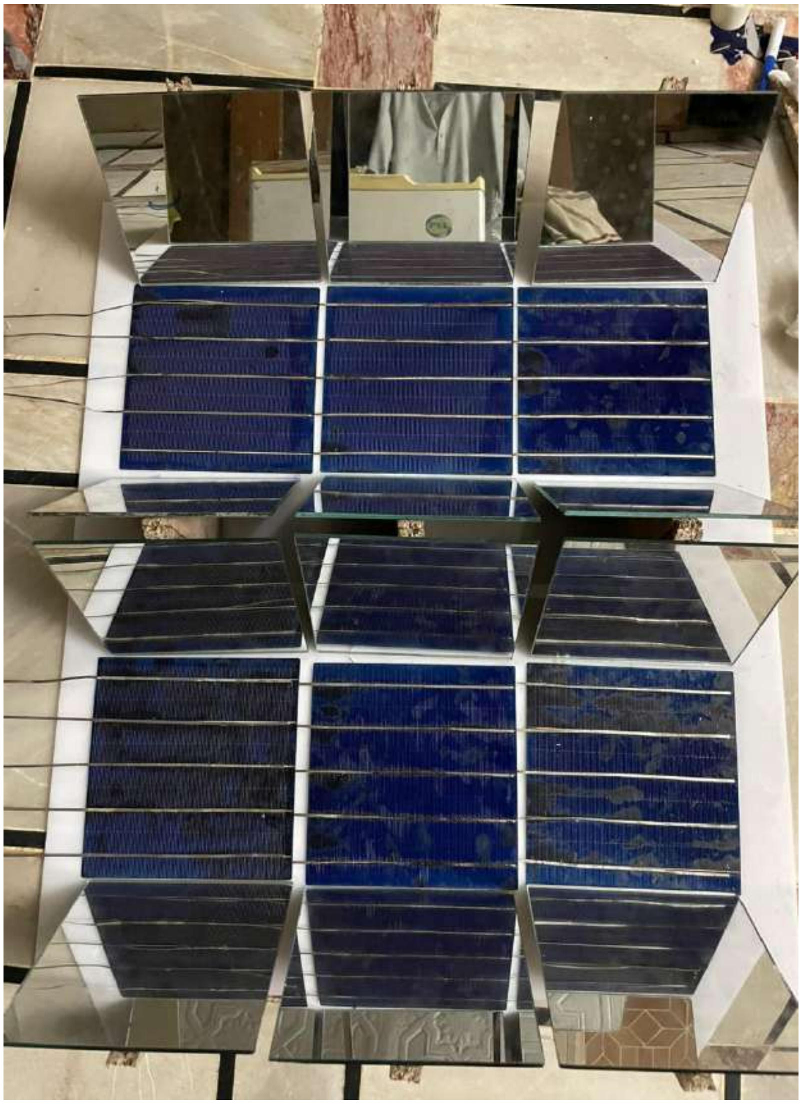


Fig 9

- **Test Cases**

The most recent test was performed on 21st march 2023 according to that test:

It's for 1 string with three cells,
the voltage without
mirrors should be
approx 1.2V theoretically
and with using mirrors 3 cells are giving 1.72volts
at 4:42 pm Tuesday while sun is not even at it's peak.

Fig 10.

- **Results/Output/Statistics:**

The results were successful since we got the expected values.

- **Completion:**

This project was completed within given time with successful results and required budget.

Chapter 5
Conclusion and Future Recommendations

- **Conclusion:**

In conclusion, concentrated photovoltaic (CPV) panels offer a compelling option to solve the limitations of standard solar technology. With their increased energy conversion efficiencies, decreased prices, optimal land management, and improved environmental sustainability, CPV panels have the potential to revolutionize solar energy generation.

By applying optical concentrators to focus sunlight onto high-efficiency solar cells, CPV panels achieve much greater energy conversion rates compared to regular PV panels. This greater efficiency translates into more electricity output per unit of sunshine, enhancing the productivity and effectiveness of solar energy systems.

Cost-effectiveness is another significant feature of CPV panels. By needing fewer solar cells and utilizing lower-cost, high-efficiency multi-junction solar cell technologies, CPV panels have the potential to cut manufacturing costs and increase affordability. This makes solar energy more accessible to a wider range of consumers, including residential, commercial, and utility-scale systems.

The optimum land usage offered by CPV panels is particularly advantageous in locations with limited space availability. By generating more electricity using a smaller surface area, CPV panels enable solar installations in urban areas, rooftops, and locations where land is scarce. This expands the possibility for solar energy deployment and makes it feasible in varied geographical settings.

Environmental sustainability is an important feature of CPV technology. By enhancing energy conversion efficiencies, CPV panels minimize the overall carbon footprint associated with solar energy output. Furthermore, the optimization of production methods and materials contributes to minimizing environmental impacts throughout the life cycle of the panels.

Overall, CPV panels offer a promising improvement in solar energy technology. Through its increased efficiencies, cost-effectiveness, optimal land usage, and reduced environmental impact, CPV panels have the potential to enable the widespread adoption of solar energy as a clean and sustainable power source. As research and development efforts continue, it is projected that CPV panels will play a vital role in crafting a brighter and greener future driven by renewable energy.

- **Future Recommendations:**

For future we would recommend to develop an efficient sun tracking system integrated with the panel to rotate it with sun.

This project should be improved further to impact several aspects in future such as:

- Technological Advancements
- Cost Reduction
- Scalability and Adaptability
- Reliability and Durability
- Market Awareness and Education

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