Analysis of Co-Generation Concentrated Solar Power System by Using Fresnel Lens and Comparison with Solar Concentrate System

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Abstract: This study examines a brand-new Concentrated Solar Power (CSP) system that heats water and generates electricity by focusing solar thermal energy onto a thermoelectric module using a Fresnel lens. The components of the setup include an infrared thermometer, heat pipes, a thermoelectric module, a platform, a water storage tank, a heat spreader plate, and a Fresnel lens. A high heat flux source is provided by the Fresnel lens, and heat pipes submerged in a water storage tank passively cool the thermoelectric module. This system maximises solar energy capture and utilisation, minimises carbon emissions, and lessens dependency on fossil fuels in order to meet the demand for effective, sustainable energy solutions.

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I. INTRODUCTION

With great potential to satisfy the world's energy needs, solar energy is a ubiquitous and sustainable energy source. Governments, businesses, and academic institutions have been working harder in recent decades to improve energy efficiency and discover fresh forms of energy. The necessity to lessen greenhouse gas pollutants and our reliance on fossil fuels is what motivates these initiatives. A key component of this shift is solar technology, which may be classified as passive or active depending on how energy is captured and converted. Solar energy is efficiently harvested by active solar technologies including photovoltaic systems, concentrated solar power, and solar water heating. Among them, systems that employ mirrors or lenses to focus sunlight are becoming more and more popular: Concentrated Solar Power (CSP) systems.

In CSP applications, a Fresnel lens is especially useful because of its propensity to focus radiation onto an extremely small region. This study looks at a CSP system that effectively produces hot water as well as energy using a thermoelectric module, heat pipes, and a Fresnel lens.

II. OBJECTIVE

This study's main goal is to develop and assess a CSP system that directs solar energy onto a thermoelectric module using a Fresnel lens. By taking use of the heat transfer from a solar collector and comparing it with other solar concentration systems, this system seeks to produce electricity and heat water.

- Constructing a CSP system configuration with heat pipes, a thermoelectric module, a heat spreader plate, and a Fresnel lens.
- Examining the manner in which the thermoelectric unit produces power from focused sun radiation.
- Assessing how well the heat pipes work to transmit heat to the water storage tank.
- Evaluating the system's general effectiveness with regard to of heating water and producing power.
- Comparison with other some effective solar concentrated system.

III. PROBLEM STATEMENT

Even though solar energy is abundant, it is still underutilised, accounting for a very small percentage of the world's electricity consumption. It is difficult for conventional solar energy systems to reach the high temperatures needed for effective energy conversion. Adequate solutions for storing are also required because solar energy is intermittent. To address rising energy demands, creative CSP systems that can effectively catch, process, and store solar energy are desperately needed. In order to meet this demand, the present research suggests a CSP system that combines a thermoelectric module's efficient energy transformation with a Fresnel lens's excellent heat flux capacity, together with heat pipes for efficient thermal control.

- *Basics of Solar Energy Technologies*

Solar energy devices use solar radiation to generate power. Such as, Homes, companies, and distant locations

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can obtain electricity with small solar energy installations. Bigger solar energy systems provide more electricity to the electrical grid by producing more electricity.

- *Solar Collectors Fall in to Two Broad Kinds.*

- The first uses non-concentrating, stationary collectors where incident radiation is intercepted and absorbed in the same space.
- Sun-tracking, concentrating solar collectors make up the second group. They use optical elements to direct a lot of energy onto a tiny receiving area and track the sun's path throughout the day to keep the greatest solar flux at its focus.

Table 1 Concentrating Technologies with Different Temperature Range

High temperature (Above 400°C)	Central Tower, Parabolic Dish
Medium temperature (100-400°C)	Parabolic Through, Fresnel Collectors
Low temperature (Below 100°C)	Flat Plate Collectors, Solar Chimney

IV. DESIGN OF SOLAR CONCENTRATORS

There have been numerous advancements in solar concentrator design during the last forty years. A few of the unique designs are shown in this publication. which have demonstrated a major impact on solar technology.

- Parabolic Through Concentrator
- Central Receiver Tower
- Linear Fresnel
- Fresnel lenses (for CPV)
- Parabolic dishes
- *Evacuated Tube*

- *Parabolic Through Collector*

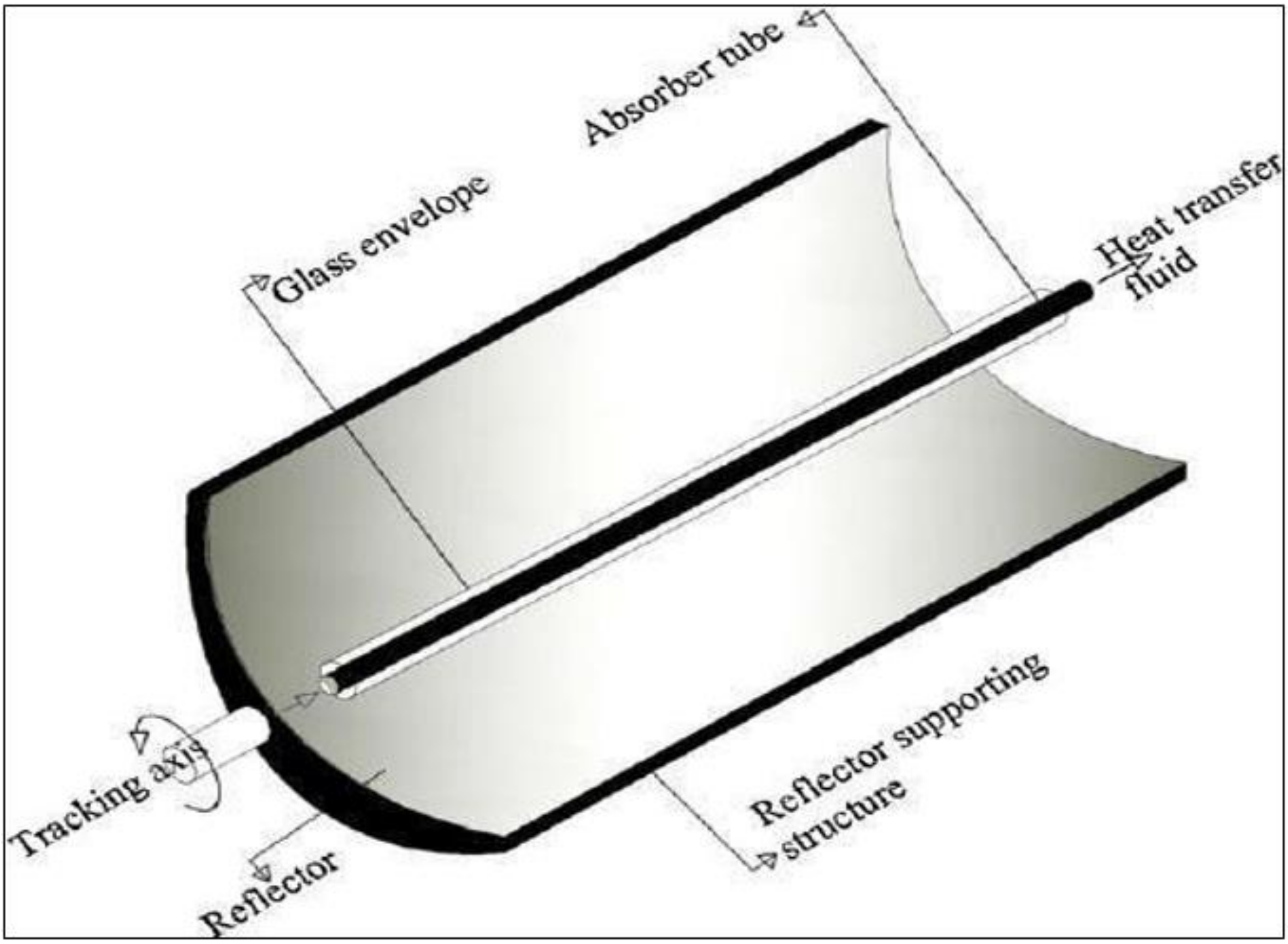

Fig 1 Parabolic Trough Shaped Lens

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As shown in Fig., parabolic trough-shaped mirrors create a focus that is linear on an antenna tube across the focal line of the parabola. The whole set of mirrors and receiver is fixed on a frame that follows the sun's daily path on one axis. The line focus moves laterally along the opposite axis in response to the sun's relative periodic movements. The line focus stays on the receiver, but there may be some spill over at the row after row, lengths. Currently, the most used CSP technique is the use of evacuated tube receivers in trough systems for thermal energy collecting. Heat from the receiver tubes is often collected and transferred to a central power block using an oil heat transfer in this fluid system.

- *Central Receiver Tower*

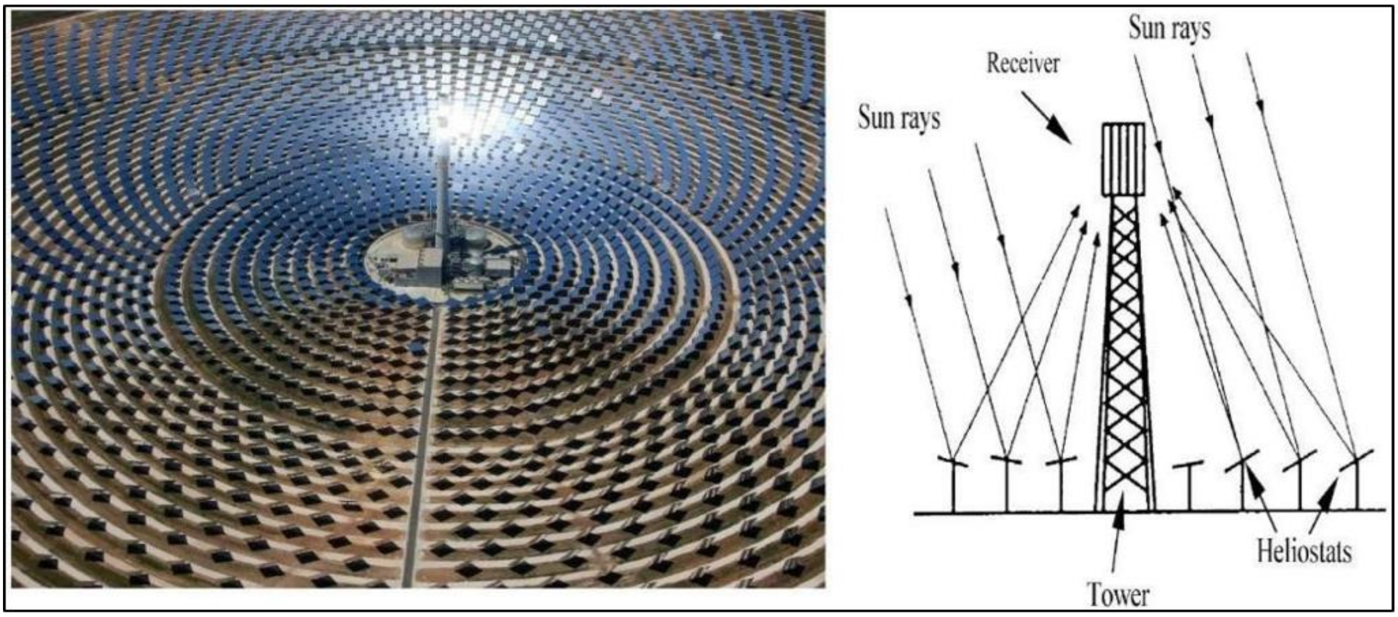

Fig 2 Central Receiver Tower

Heliostat solar towers, sometimes called central receiver solar towers, are made up of thousands or even hundreds of tiny reflectors positioned on the ground. These reflectors focus the sun's rays onto a central receiver positioned atop a stationary tower. This enables complex energy conversion with excellent effectiveness at a single, sizable receiver point. In comparison to linear focusing systems, larger concentration ratios are attained, enabling thermal receivers to function at higher temperatures with lower losses. It operates in the high temperature range of more than 400 °C.

- *linear fresnel*

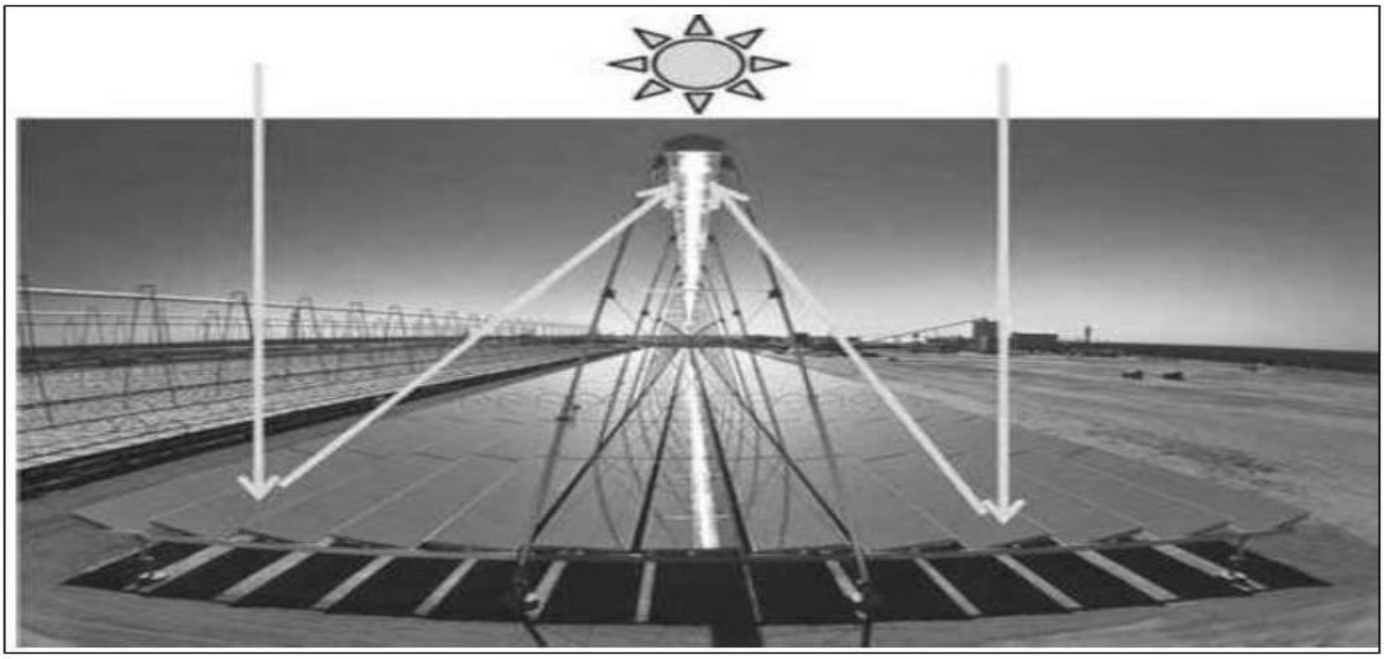

Fig 3 Linear Fresnel

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As illustrated in Fig., linear focus is produced on a downward facing fixed receiver using linear Fresnel reflector (LFR) systems installed on a number of tiny towers. Mirrors arranged in long rows, either flat or slightly curved, move freely on one axis to reflect sunlight onto a stationary receiver. Because the fixed receiver has a continuously down facing chamber, it can help reduce convection losses from a thermal receiver and eliminate the requirement for rotational joints for the heat transfer fluid in thermal systems. The LFR approach's supporters contend that the system's straightforward design, which has fewer supporting structures and nearly flat mirrors, makes up for its lower overall optical and (for CST) thermal efficiency. The system is also closer to the ground.

- *Fresnel lens*

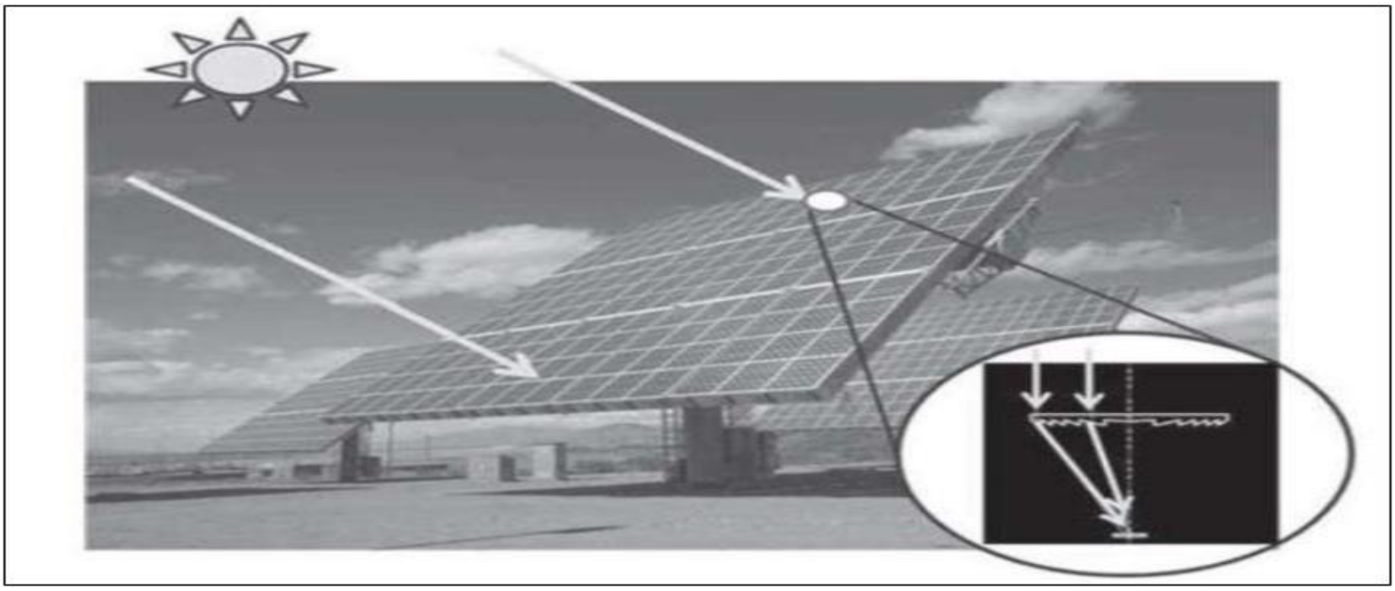

Fig 4 Fresnel lens

It is costly and impracticable to produce a typical lens in big quantities. Because it solves these problems, the Fresnel lens is widely used in CPV systems. A Fresnel lens is constructed from a sequence of closely spaced, concentric tiny steps, each of which has a surface form similar to that of a regular lens but is kept within a narrow thickness. As seen in Fig.1-4, arrays of several lens components are normally installed on a heliostat construction using a plastic material. This method is also point-focused and necessitates precise two-axis sun tracking. Below 400°C is the medium temperature range for which it is employed.

- *Parabolic dishes*

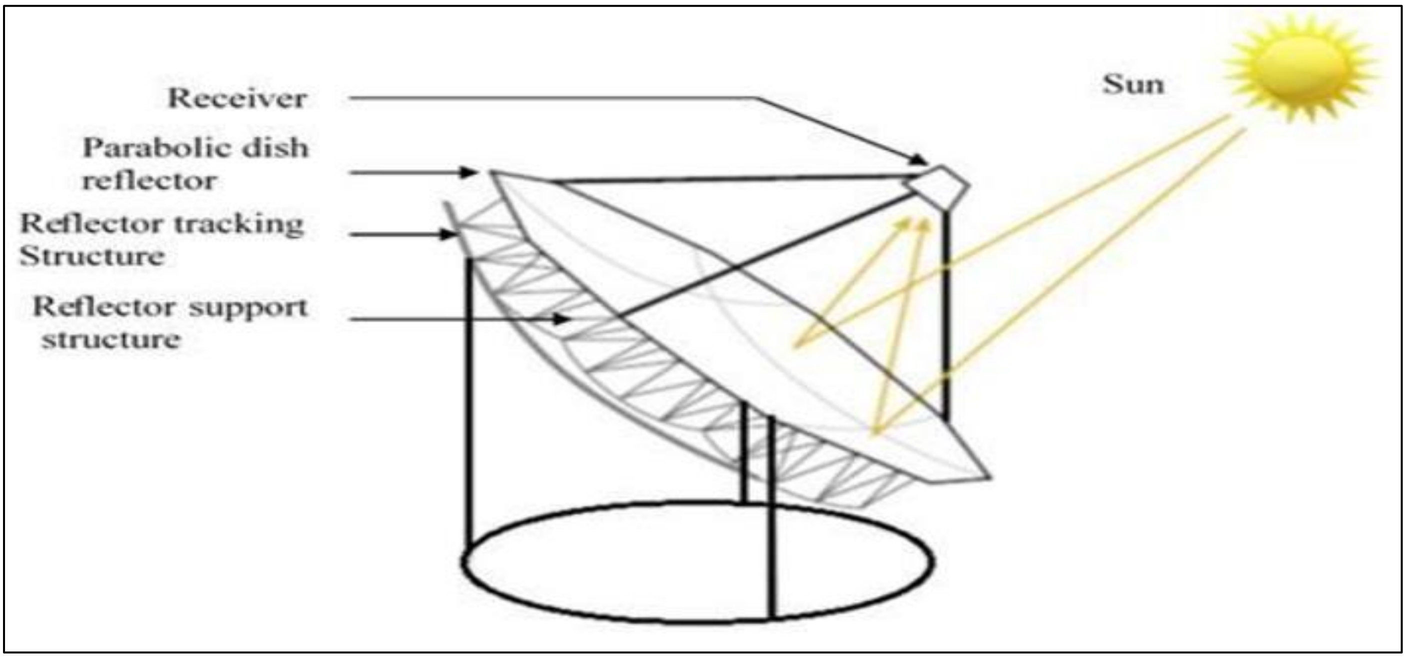

Fig 5 Parabolic Dishes Lens

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In CST systems, the reflected direct beam radiation is focused to a point focus receiver, which can be heated to operational temperatures of more than 1,000ºC, much like in tower systems. Of all the CSP technologies, dish systems have the highest possible solar conversion efficiencies because they never experience the cosine loss effect and always face the sun with their full aperture. But they are the least developed economically. There have been demonstrations of dishes up to 24 m in diameter. In addition to its well-established use with thermal conversion, CPV conversion is also applied to micro dishes, which have a diameter of only a few centimetres. Parabolic dishes have a high starting cost but are easy to operate, have a simple structure, and can reach temperatures beyond 400°C.

V. THE WAY A FRESNEL LENS SOLAR CONCENTRATOR WORKS

A Fresnel lens is a basic tool used to focus solar thermal energy or light from the sun onto a limited region. Solar energy is of low quality, and the Fresnel lens is used to collect the majority of the energy needed at temperatures between moderate and high. The energy above 100 °C can be upgraded to 300 °C.

➢ *Application*

- Residential Use: providing electricity and hot water for homes, reducing reliance on traditional power grids and water heating systems.
- Commercial building: Supplying power and hot water to offices, hotels and other commercial establishments, leading to energy cost savings and sustainable building practices.
- Remote locations: offering a reliable energy solution for off grid areas where access to electricity and hot water is limited.
- Industrial process: supporting industrial applications that require both electricity and hot water or steam such as food processing, textile manufacturing and chemical production.
- Agriculture: heating water for irrigation systems and generating power for agricultural equipment in rural areas.

➢ *Advantages*

- Dual functionality: the system generates both electricity and hot water, maximizing the use of capture solar energy.
- Renewable energy: utilizes abundant and renewable solar energy, reducing dependences on fossil fuels.
- Environmental impact: Lowers carbon dioxides emissions and promotes sustainable energy practices.
- Cost efficiency: Potentially reduces energy costs by providing free solar energy after initial setup.
- Scalability: Can be scaled to meet different energy demands, from small residential units to large industrial installations.
- Thermal energy store: The system’s ability to store thermal energy enhances reliability and provides power during non-sunny periods.

➢ *Disadvantages*

- Initial cost: high initial investment costs for setting up the system, including the Fresnel lens, thermoelectric module and heat pipes.
- Maintenance: Require regular maintenance to ensure optimal performance, especially for the Fresnel lens and heat pipes.
- Weather dependency: Performance is highly dependent on sunlight availability, which can be inconsistent due to weather conditions.
- Space requirements: Requires sufficient space for installations, particularly for the Fresnel lens to capture and concentrated sunlight effectively.
- Heat management: Effective heat management is crucial to prevent overheating and ensure the longevity of the thermoelectric module and other components.

VI. LITERATUTE REVIEW

An experimental analysis of several thermal systems emitting a considerable quantity of waste energy recovery was provided by Nabil A.S. Elminshawy and Farooq R. Siddiqui. Developing an effective desalination system in conjunction with solar energy is the primary objective of this energy. In order to investigate the impact on daily portable water productivity, this experiment was conducted in Saudi Arabia with varying waste gas flow rates and 12 variable evaporator inlet water temperatures. An evaporator, condenser, air blower, electric heater, storage tank, and evacuated tube solar collector made up the suggested configuration. Up until the critical flow rate, it was discovered that raising the hot air flow rate increased water production; after that, productivity decreased.

The total daily (9 AM–5 PM) portable water production of the suggested system is around 50 L, with matching useful waste heat fluctuations of 130–180 MJ/day and global solar radiation fluctuations of 15–29 MJ/m2/day on a horizontal surface. With the suggested desalination system, water is generated for 0.014 USD/L and fuel savings of 1844 kg/h are realised.

A water desalination system and thermoelectric power generating experimental setup were presented by Abhijit and Ashwin Date. In the suggested system, thermoelectric generators for power generation and water desalination are heated by low-grade thermal radiation. Together with experimental validation, a theoretical analysis provides the governing equations to estimate the system's performance characteristics, and An evaporator vessel, heat pipes, thermoelectric modules, an electric heat source, and a heat sink make up the experimental setup. To passively cool the underside of the thermoelectric cells, four heat pipes are arranged in a heat spreader block.

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The condenser portion of the heat pipes is submerged in a saltwater pool kept at sub- atmospheric pressure in an evaporation tank. In this research, it was found that one could anticipate the system's transient and steady state behaviour by considering the value for the rate of heat loss from the saline water. Decreasing the level of pressure in the salted water tank could raise the limit heat flux for a TEG with a cell failure temperature of 250℃. It was found that at barely saturated temperatures, a higher heat flow could be provided to the thermoelectric generators while reducing heat loss into space.

Kangmin Park, jeong Kim, Jin-Geun Rhee, and Kwangsun Ryu presented a novel design for solar concentration optics that produced a moderate concentration ratio and homogeneous intensity on the absorber plane by using a modularly faceted Fresnel lens. Fresnel lenses that are modularly facetted yield a consistent brightness. The low-cost 3-D concentration solar photovoltaic (PV) system is intended for use in future applications and utilises the idea of modularly faceted Fresnel lenses.

VII. RESULTS

- ➢ The proposed CSP system theoretically promises an efficient method for generating electricity and heating water by leveraging the combined effects of a Fresnel lens and thermoelectric module.
- ➢ The system design suggests that Electricity Generation: The thermoelectric module can achieve notable conversion efficiency when exposed to concentrated sunlight, providing a steady output of electricity.
- ➢ Water Heating: The heat pipes effectively transfer heat from the thermoelectric module to the water storage tank, potentially raising water temperatures significantly over extended periods.
- ➢ System Efficiency: Overall system efficiency, including both electrical and thermal outputs, could be estimated to be around 25%, making it a viable option for dual energy needs.
- ➢ Sunlight is focused onto a tiny surface area on a copper heat spreader plate using a Fresnel lens. The plate has a concentrated area of about 1500 x 850 mm^^2.In order to keep the thermoelectric module's hot side temperature at or below 300°C, different heat fluxes were applied across it. The heat pipe and heat flux delivered to the water passively cool the thermoelectric module's cold side. Never does the temperature of the water get above 100°C.

COMPARISON WITH OTHER SOLAR PANELS

Traditional photovoltaic (PV) panels and Concentrated Solar Power (CSP) systems serve different purposes and operate based on different principles:

➢ Photovoltaic (PV) Panels:

- Efficiency: Typically, around 15-20%.
- Energy Conversion: Directly convert sunlight into electricity using semiconductor materials.
- Temperature Dependence: Efficiency decreases with increased temperature.
- Application: Commonly used for residential, commercial, and utility-scale power generation.
- Storage: Often paired with battery storage systems.

➢ *Concentrated Solar Power (CSP) Systems:*

- Efficiency: Can exceed 20% depending on the technology and configuration.
- Energy Conversion: Use mirrors or lenses to concentrate sunlight onto a small area to produce high temperatures, which then drive a thermodynamic cycle or thermoelectric conversion.
- Temperature Dependence: Operate more efficiently at higher temperatures.
- Application: Typically used for large-scale power generation and industrial applications.
- Storage: Often includes thermal energy storage systems, such as molten salt, to provide power during non-sunny periods.

VIII. CONCLUSION

The study demonstrates that a CSP system using a Fresnel lens and a thermoelectric module can effectively generate electricity and heat water simultaneously. While traditional PV panels offer straightforward electricity generation, the proposed CSP system provides a dual benefit, making it suitable for applications requiring both electricity and thermal energy. This system also highlights the potential for integrating thermal energy storage to enhance the reliability and efficiency of solar energy utilization. Further research and optimization can improve the efficiency and scalability of such systems, contributing to the global shift towards renewable energy sources. Also suggested that by harnessing solar radiation, the device can provide both hot water and electrical energy. heat transfer via a thermoelectric module from a solar collector to a hot water storage tank. In order to produce a high heat flux in the experimental system, concentrated solar thermal devices like Fresnel lenses are recommended as the heat source for thermoelectric power generation. Thermoelectric modules can generate power for temperature differences because their cold side is passively cooled by a heat pipe, and their extracted heat input heats the water in storage tanks in a steady state.

FUTURE SCOPE

The development and optimization of the proposed concentrated solar power system utilizing a Fresnel lens and thermoelectric module open numerous avenues for future research and application:

- ➢ Hybrid systems: Combining CSP with tradition photovoltaic panels could create hybrid systems that maximizes solar energy utilization by generate both electricity and heat.

- Efficiency Improvements: Research into advanced thermoelectric materials with higher conversion efficiencies could significantly enhance the system's performance. Improvements in Fresnel lens design and materials could increase the concentration ratio and overall system efficiency.
- Modularity: Developing modular CSP units that can be easily scaled up or down depending on the energy needs of different applications, from small residential setups to large industrial plants. Creating portable CSP systems for temporary installations or use in disaster relief scenarios where rapid deployment of energy solution is needed. Smart integration enhancing the compatibility of CSP systems with smart grids to facilitate seamless energy distribution and integration with other renewable energy sources.
- Environmental and economic analysis: Analyzing the long-term economic benefits and payback periods for different scales of implementation to promotes wider adoption.
- Global deployment: adapting the CSP system design for optimal performance in various geographical regions with different solar insolation levels.

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