

# Utilization of Energy Conversion Machines in Solar Power Systems

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## Article Info

### Article history:

Received 4 March, 2024

Revised 29 June, 2024

Accepted 28 July, 2024

### Keywords:

*Solar Energy;  
Photovoltaic Technology;  
Solar Thermal Collector;  
Stirling Engine*

## ABSTRACT

The utilization of solar energy as an alternative energy source is becoming increasingly important in the face of dependence on fossil fuels and reducing greenhouse gas emissions. This study analyzes the use of various energy conversion machines in solar power systems, including photovoltaic technology, thermal solar collectors, and Stirling engines. Advances in photovoltaic technology, such as the use of perovskite materials and tandem solar cells, have improved the efficiency of converting solar energy into electricity. Innovations in thermal solar collectors, including the use of nanofluids and solar concentrator designs, have also improved the efficiency of thermal energy collection. Stirling engines show great potential in solar power systems due to their high efficiency and ability to work with a variety of heat sources. This research also discusses challenges and solutions in the implementation of this technology, including initial costs, efficiency affected by weather conditions, and the importance of efficient energy storage systems. Policy support, financial incentives, and collaboration between government, industry, and research institutions are identified as key factors to accelerate the adoption of solar technology. The social and environmental impacts of solar technology implementation are significant, including reduced greenhouse gas emissions, improved energy access in remote areas, and contribution to national energy security. This research contributes to the development of renewable energy technologies and supports the transition to a more sustainable energy system.

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## INTRODUCTION

The utilization of solar energy as an alternative energy source has become a major focus in various research and development of renewable energy technologies. Abundant and environmentally friendly, solar energy offers a potential solution to overcome dependence on fossil fuels and reduce greenhouse gas emissions. Amidst the increasing awareness of environmental and sustainability issues, the integration of energy conversion technologies in solar power systems has become very important. Energy conversion machines are devices that convert energy from one form to another. In the context of solar power, they play an important role in converting solar energy into usable electrical energy or thermal energy. This technology includes various systems such as solar photovoltaic (PV) panels, thermal solar collectors, and thermodynamic engines such as Stirling and Rankine engines that utilize solar heat to generate electricity (1).

The development of photovoltaic technology has progressed rapidly in recent decades. New materials such as perovskite and organic-based solar cell technologies promise higher efficiency and lower production

costs (2). However, a major challenge in the utilization of solar panels is the fluctuation of sunlight intensity, which impacts the consistency of energy production. Therefore, research into efficient energy storage and conversion systems is highly relevant (3). Besides photovoltaics, solar thermal collectors also play an important role in solar power systems. These collectors collect heat from sunlight and use it to heat the working fluid. The heat generated can be used for domestic, industrial purposes, or converted into electrical energy through thermodynamic machines. Research on the efficiency of solar collectors and optimization of their design is constantly evolving to maximize the utilization of solar energy.

Stirling engines, as one of the thermodynamic engines, have great potential in solar power systems (4). This engine works by utilizing the temperature difference between two heat sources to produce mechanical motion which is then converted into electricity. The main advantages of the Stirling engine are its high efficiency and its ability to work with various heat sources, including solar heat (5). The integration of Stirling engines in solar power systems can improve the overall efficiency and reliability of the system. Research on energy conversion engines in solar power systems also includes aspects of energy storage. Energy storage is a key component to ensure energy availability when there is insufficient sunlight, such as at night or in cloudy weather. Integrating Stirling machines into solar power systems can contribute significantly to sustainable energy solutions (6). Thermal energy storage technology and batteries are the main focus of this research. The development of efficient and low-cost storage systems will increase the competitiveness of solar power as a primary energy source.

This research aims to analyze and evaluate the utilization of different types of energy conversion machines in solar power systems, focusing on improving the efficiency and reliability of converting solar energy into electrical and thermal energy. In addition, this research aims to identify the latest technologies, efficient energy storage methods, and policies that support the widespread adoption of solar power technologies. The novelty of this research lies in its comprehensive approach of integrating various energy conversion technologies-including photovoltaics, solar thermal collectors, and Stirling machines-with innovative energy storage systems. In addition, it explores new materials and designs to improve energy conversion efficiency and investigates policy and economic impacts in depth to encourage practical implementation in various geographic and social contexts.

The successful utilization of energy conversion machines in solar power systems depends not only on the technology itself, but also on economic and regulatory factors. Research should consider the cost of production, installation and maintenance of the system as well as government incentives for renewable energy. Policies that support the use of solar energy, such as subsidies and tax incentives, will encourage wider adoption of this technology. In recent years, there has been rapid progress in SC (Solar Cells) research, mainly focused on improving efficiency and reducing costs (7). So far, many solar power applications have been implemented on a small, medium, and large scale (8). In addition, social and environmental aspects must also be considered. Public education and awareness about the benefits of solar energy and its impact on the environment need to be improved. Research on the environmental impact of solar technology production and use is also important to ensure that the energy solutions implemented are truly sustainable. Increasing concern for the environment and positive attitudes towards sustainable types of energy have played an important role in the development of renewable energy (9). Thus, the background of this research shows the importance of the integration of energy conversion machines in solar power systems as an effort to improve the efficiency and reliability of solar power systems. This research is expected to make a significant contribution to the development of renewable energy technologies and support the transition to a more sustainable energy system.

## METHODOLOGY

This research used the literature study method to analyze and evaluate the utilization of energy conversion machines in solar power systems. The initial stage involved collecting literature from various sources such as scientific journals, books, conference articles, dissertations, and research reports using academic databases such as Google Scholar, IEEE Xplore, ScienceDirect, and university libraries, with the keywords "energy conversion engine", "solar power system", "photovoltaic solar panel", "thermal solar collector", and "Stirling engine". Once the literature was collected, a critical analysis of the selected publications was conducted to assess the research methods, data, and results and conclusions, in order to identify knowledge gaps and discover research areas that require further exploration. Next, this study develops a theoretical framework and hypotheses based on the findings from the literature analysis, which will then be tested in subsequent empirical research. The results of the literature study are synthesized in the form of a comprehensive literature review that includes an introduction, discussion of key findings, identification of research gaps, and conclusions, which is then published for the academic community and practitioners in the field of renewable energy. With a systematic literature study method, this research is expected to make a significant contribution to the understanding and development of solar energy conversion technology and provide recommendations for further research and practical implementation.

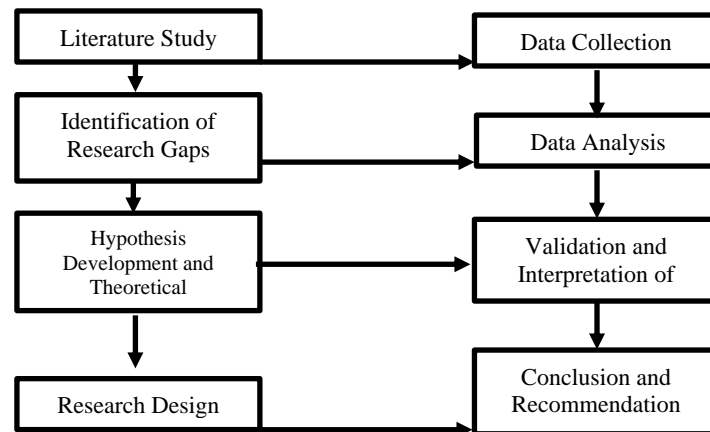


Figure 1. Research Framework: Utilization of energy conversion machines in solar power systems

This research uses the literature study method as the main approach to analyze and evaluate the utilization of energy conversion machines in solar power systems. The first step was to collect, analyze, and synthesize existing information on energy conversion technology and solar power systems. The next step is to identify research gaps by finding untapped or limited research areas and identifying unanswered research questions. Based on the results of the literature study, this research then formulated hypotheses and developed a theoretical framework as the basis of the research. Next, the research design was designed by determining the research methods, including the experimental design, data collection techniques, and analysis tools to be used. Data collection was conducted through laboratory experiments, computer simulations, or field studies according to the research needs. The collected data is analyzed to identify trends, patterns, and relationships between variables. Afterwards, the results of the analysis were validated with existing data or case studies, and the research findings were interpreted to gain a deeper understanding. Finally, the study draws conclusions based on the research results and provides recommendations for further research or practical applications. This systematic approach ensures that the research is thorough and makes a significant contribution to the understanding and development of solar energy conversion technology.

## RESULTS AND DISCUSSION

This research successfully collected and analyzed various relevant literature regarding the utilization of energy conversion machines in solar power systems. From this analysis, some key findings can be concluded:

### Improving the Efficiency of Photovoltaic Technology:

Improving the efficiency of photovoltaic (PV) technology has been a major focus in solar energy research and development. One significant advance has been the use of new materials such as perovskites, which have shown the potential to drastically improve the efficiency of converting solar energy into electricity. Perovskite solar cells have achieved efficiencies of more than 25% under laboratory conditions, approaching and in some cases exceeding the efficiency of conventional silicon solar cells. With the rapid progress in power conversion efficiency (PCE) to reach 25%, metal halide perovskite-based solar cells have shown significant progress in the photovoltaic field (10). Studies have shown that PV-TE-HW hybrid systems can improve the efficiency of photovoltaic panels (11). In addition, perovskites can be produced at a lower cost and at lower temperatures compared to silicon, making them attractive for future commercial applications. For the commercialization of perovskite photovoltaic (PV) technology, achieving high power conversion efficiency (PCE), long lifetime, low toxicity, scalable fabrication protocols, optimized large-area solar module structures, and positive cost-benefit assessment are essential (12).

In addition to perovskites, the development of tandem solar cells has also made a great contribution to the improvement of efficiency. Tandem solar cells combine two or more layers of different photovoltaic materials to utilize the sunlight spectrum more efficiently. For example, the combination of perovskite solar cells with silicon solar cells has demonstrated efficiencies of over 29%, with the potential to achieve efficiencies above 30% in the near future. This approach allows for more optimal utilization of various wavelengths of light, thereby increasing the total energy output.

In addition to material innovations, improvements in the efficiency of photovoltaic technologies are also achieved through surface engineering and novel designs. Technologies such as micro and nano surface texturing and anti-reflection coatings can increase light absorption and reduce losses due to reflection. New designs on solar cell structures, such as the use of full back contacts or heterojunctions, also contribute to the reduction of recombination losses and the improvement of electric current collection efficiency. Together, these innovations not only improve solar cell efficiency but also reduce manufacturing costs and extend the

operational life of solar panels, making photovoltaic technology increasingly competitive as a renewable energy source.

In the field of solar energy and photovoltaic technology, research has been conducted on various aspects to improve efficiency and performance. ZnO/ZnS has been explored as an electron transport material in Perovskite Solar Cells (13). This study contributes to the development of tandem solar cells by investigating new materials to improve performance. In addition, the impact of TiO<sub>2</sub> nanoparticle thin film thickness on the optical and electrical properties of Perovskite solar cells has been analyzed (14). This research emphasizes the importance of material optimization in improving solar cell efficiency and converting solar energy into electricity effectively.

#### **Innovations in Solar Thermal Collectors:**

Innovations in solar thermal collectors are constantly evolving to improve the efficiency of collecting and converting solar energy into thermal energy. One key innovation is the use of new materials that have superior thermal properties, such as nanofluid-based heat transfer fluids (15). Nanofluids, which consist of nanoparticles suspended in a base fluid, show significant improvements in heat capacity and thermal conductivity. This allows thermal solar collectors to absorb and transfer more heat with higher efficiency compared to conventional heat transfer fluids, such as water or oil.

New designs in solar thermal collectors also play an important role in efficiency improvement. Concentrator solar collectors (CSPs), for example, use mirrors or lenses to focus sunlight onto a smaller, hotter area, increasing the operating temperature. By focusing sunlight, CSP systems can reach very high temperatures, which can be used to drive steam turbines or Stirling engines, generating electricity with high efficiency. This design not only increases energy conversion efficiency but also allows for the storage of thermal energy for use when the sun is not shining. Parabolic collectors and heliostats are examples of these technologies that have been used in solar power generation. In addition, thermal performance improvements in parabolic trough solar collectors using absorber tubes with inner helical axial fins have been explored (16) and the performance of oil-based thermal storage systems with parabolic trough solar collectors using nanofluids has been investigated (17). The integration of phase change material thermal storage technology in solar collector systems for residential applications has been discussed (18).

In addition, innovations in heat storage materials have improved the performance of thermal solar collectors. Phase change materials (PCMs) and sensible heat storage materials can store thermal energy collected during periods of high sunlight and release it when needed, such as at night or during cloudy weather. PCMs, in particular, can store and release energy in a latent form when undergoing a phase change, making them highly efficient in thermal energy storage. The integration of these storage technologies with solar thermal collectors ensures a stable and continuous supply of energy, improving the reliability and overall performance of the solar thermal power system. These innovations show how solar thermal collector technology is constantly evolving to meet the growing energy needs in a more efficient and sustainable way.

#### **Use of Stirling Engines in Solar Power Systems:**

The use of Stirling engines in solar power systems offers an efficient solution to convert solar energy into mechanical energy and then into electricity. Stirling engines work on the principle of a closed thermodynamic cycle, in which a working gas (usually helium or hydrogen) is heated by an external heat source, such as a solar collector, and cooled by a cold source. This heating and cooling process causes the gas to expand and contract, driving a piston that produces mechanical motion. The main advantages of the Stirling engine are its ability to operate with a variety of heat sources and its high efficiency over large temperature differences, making it ideal for solar power applications.

The integration of Stirling engines with thermal solar collectors shows great potential in improving the efficiency of solar power systems. Thermal solar collectors, such as parabolic troughs or heliostats, can focus sunlight to heat a working fluid to very high temperatures. This collected heat is then used to drive a Stirling engine. With optimal design and materials, Stirling engines can achieve high thermal conversion efficiency, generating electricity with very low emissions. In addition, because Stirling engines have few moving parts and operate without internal combustion, they tend to be more durable and require less maintenance than conventional engines.

Technological advances in the materials and design of Stirling engines continue to improve their performance in solar power applications. The use of materials capable of withstanding high temperatures and improvements in cooling system design help to increase the efficiency and reliability of Stirling engines. In addition, the development of hybrid systems that combine the Stirling engine with thermal energy storage or batteries increases the flexibility and stability of the power supply. For example, thermal energy generated during the day can be stored and used to power the Stirling engine at night or during cloudy weather. These innovations make the Stirling engine a critical component in a sustainable and efficient solar power system, helping to address the challenges of energy availability and greenhouse gas emissions.

Research on solar power applications in Indonesia is increasingly showing its relevance and potential. The initiation of micro-enterprises in the implementation of solar power plants in Majalaya Village, Cianjur, has been discussed (19). In addition, the performance of a solar water pumping system in Trombol Village, Mondokan District, Sragen Regency has been analyzed (20). The performance of a solar parabolic Stirling engine for the needs of remote areas in the Indonesian Journal of Mechanical Engineering has been evaluated (21). All of these studies show that the application of solar technology, both through Stirling engines and water pump systems, has great potential to improve energy efficiency, reduce emissions, and support sustainable development in various regions, including remote areas. The integration of these technologies not only improves the efficiency and reliability of solar power systems, but also supports local initiatives and community development through environmentally friendly and sustainable energy solutions.

### **Implementation Constraints and Solutions:**

The implementation of solar energy conversion technologies, while promising, faces a number of obstacles that need to be overcome to achieve widespread and sustainable adoption. One major obstacle is the high initial cost associated with the installation of solar power systems, including photovoltaic panels, solar thermal collectors, and energy conversion machines such as Stirling engines. Although the cost of solar technology has decreased in recent years, the significant initial investment is still a barrier for many users, especially in developing countries and remote areas. The efficiency of the technology is also a significant obstacle. While there have been improvements in the energy conversion efficiency of photovoltaic panels and thermal solar collectors, it is still affected by weather conditions and time of day. For example, the efficiency of solar panels decreases during cloudy weather or at night. Likewise, thermal solar collectors require sufficient sunlight to function optimally. Therefore, efficient energy storage systems are crucial to overcome these fluctuations and ensure a stable energy supply. Energy storage technologies, such as lithium-ion batteries and phase change materials (PCMs), are being developed to improve the efficiency of solar energy storage and use.

In addition to technical and cost constraints, regulatory and policy challenges also play an important role in the implementation of solar technologies. In many countries, unsupportive energy policies or insufficient incentives can hinder the development and adoption of renewable energy technologies. However, several solutions have been identified to overcome these obstacles. Strong policy support from the government, such as subsidies, tax incentives, and financing programs, can help reduce initial costs and encourage investment in solar technology. Training and education programs are also important to increase awareness and understanding of the benefits of solar energy among the public and industry players. To overcome these constraints, collaboration between government, industry and research institutions is essential. Continuous technological innovation, consistent policy support, and increased public awareness can together help accelerate the adoption of solar technology. Thus, comprehensive and integrated solutions are needed to overcome implementation constraints and maximize the potential of solar energy as a clean and sustainable energy source in the future.

Various studies have highlighted the challenges and solutions related to renewable energy integration. The challenges and solution technologies for integrating variable renewable energy sources has been discussed (22). The focus on the application of social equity in public policy design, specifically analyzing solar energy equity policies has been discussed (23). The current prospects of building-integrated solar PV systems and bifacial PV applications has been explored (24). Akimov examined the readiness of Australia's regulatory and policy framework for an energy transition led by distributed energy resources (25). All of these studies show that overcoming barriers to solar energy implementation requires a holistic and collaborative approach. With the right policy support, technological innovation, and increased public awareness, solar energy's potential as a clean and sustainable energy source can be optimized to support sustainable global development.

### **Social and Environmental Impacts:**

The research also highlighted the positive impacts of using solar technology on the environment and society. Reduced greenhouse gas emissions, improved energy access in remote areas, and contribution to national energy security are some of the key benefits identified. In addition, the adoption of these technologies can create new jobs and support sustainable economic growth. The implementation of solar energy conversion technologies has significant and positive social and environmental impacts. From an environmental perspective, the use of solar energy directly reduces dependence on fossil fuels, which are a major source of greenhouse gas emissions and air pollution. By replacing carbon-based energy with renewable energy, such as solar power, we can reduce CO<sub>2</sub> emissions and other pollutants that contribute to climate change and public health issues. In addition, solar technology does not produce harmful emissions during its operation, helping to maintain air quality and reduce negative impacts on ecosystems.

From a social standpoint, solar power offers extensive benefits especially in remote and less developed areas. In regions unreachable by conventional power grids, solar power systems can provide stable and affordable energy access. This enables improved quality of life, by providing electricity for basic needs such as lighting, heating, cooling, and charging electronic devices. In addition, access to reliable energy can boost local economic activity, allowing small and medium-sized enterprises to expand and create new jobs.

The adoption of solar technology has also had a positive impact on the education and health sectors. In schools that previously had no access to electricity, the installation of solar panels enables the use of modern educational equipment and adequate lighting, thus supporting a better teaching and learning process. In the health sector, medical facilities in remote areas can use solar energy to operate essential medical equipment, store vaccines, and provide adequate lighting, thereby improving the quality of health services. Thus, the adoption of solar technology not only helps preserve the environment but also contributes to sustainable social and economic development.

Various studies have highlighted the environmental and social impacts of implementing solar technologies. The environmental assessment of a solar-biomass hybrid energy supply system, suggesting that this combination could provide a more sustainable energy solution has been discussed (26). The concept of solar trees as a sustainable energy approach for farmers, which can increase agricultural productivity and provide reliable energy has been explored (27). Overall, the application of solar technologies has great potential to address global energy and environmental challenges. With the right policy support, technological innovation, and increased public awareness, solar technology can be an effective solution to achieve sustainable development and reduce negative impacts on the environment and society.

## CONCLUSION

This study concludes that energy conversion technologies in solar power systems show great potential in providing clean, efficient and sustainable energy sources. Innovations in materials and design, such as the use of perovskites in photovoltaic cells, the development of more efficient thermal solar collectors, and the integration of Stirling engines, have improved energy conversion efficiency and reduced manufacturing costs. Although challenges such as high initial costs, efficiency variability, and the need for efficient energy storage systems remain, strong policy support, financial incentives, and collaboration between government, industry, and research institutions can help overcome these obstacles and accelerate the adoption of solar technologies.

The social and environmental impacts of implementing solar technology are significant. The use of solar energy can reduce greenhouse gas emissions, help mitigate climate change, and improve air quality. Socially, the technology offers great benefits especially in remote areas, by providing stable and affordable energy access, which in turn can boost economic activities, improve the quality of education, and enhance health services. Thus, solar energy conversion technology not only helps preserve the environment but also contributes to sustainable social and economic development.

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