

# Design of Solar Module for Enhanced Renewable Energy Harvesting

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*Abstract - Solar energy is widely recognized as one of the most abundant and sustainable renewable energy sources available for meeting the world's growing energy demands. However, conventional photovoltaic (PV) systems often require extensive land area for installation, which limits their feasibility in densely populated urban environments where space is a critical constraint. To address this challenge, the concept of the solar tree has emerged as an innovative and space-efficient alternative. A solar tree is a structure designed to mimic the form of a natural tree, where solar panels are arranged like branches to capture maximum sunlight throughout the day while occupying minimal ground space.*

*This paper explores the fundamental design and working principle of solar tree technology, emphasizing how its vertical and multi-directional panel arrangement enhances solar energy absorption compared to traditional flat-panel systems. The study also examines the key advantages of solar trees, including efficient land utilization, improved energy output per unit area, and aesthetic integration into urban landscapes. Additionally, the paper highlights various applications of solar trees, such as in urban infrastructure, public spaces, educational institutions, and smart city initiatives.*

*Recent technological advancements—such as improved photovoltaic materials, smart tracking systems, and energy storage integration—have significantly enhanced the performance and feasibility of solar tree systems.*

*The paper also discusses the future scope of solar tree technology, focusing on its potential role in sustainable urban development and decentralized energy generation. With ongoing innovation and increasing emphasis on clean energy solutions, solar trees are expected to become a viable complement to traditional solar installations.*

## I. INTRODUCTION

The rapid increase in global energy demand, coupled with the continuous depletion of fossil fuel resources, has accelerated the need for sustainable and renewable energy solutions. Conventional energy sources such as coal, oil, and natural gas not only face the challenge of limited

availability but also contribute significantly to environmental degradation and climate change. In this context, solar energy has emerged as one of the most reliable and environmentally friendly alternatives. Being abundant, clean, and renewable, solar energy plays a crucial role in addressing current and future energy requirements while supporting sustainable development goals.

Despite its advantages, the widespread adoption of solar energy through traditional photovoltaic (PV) systems faces certain limitations. Conventional solar panels are typically installed on large, flat surfaces such as rooftops or open land. This requirement makes them less suitable for densely populated urban areas where space is scarce and expensive. Additionally, large-scale solar installations may not always align with urban aesthetics, posing challenges for integration into city landscapes. These limitations highlight the need for innovative approaches that can efficiently utilize available space without compromising energy generation capacity.

To overcome these challenges, the concept of the solar tree has been introduced as a novel and practical solution. A solar tree is a specially designed structure that replicates the form of a natural tree, with solar panels arranged like leaves on its branches. This biomimetic approach allows for the vertical arrangement of panels, significantly reducing the ground area required for installation. By positioning panels at different heights and angles, the design ensures maximum exposure to sunlight throughout the day, thereby improving overall energy efficiency.

Furthermore, solar trees offer additional benefits beyond energy generation. Their visually appealing design makes them suitable for integration into public spaces such as parks, campuses, streets, and commercial complexes. This not only enhances the aesthetic value of the surroundings but also promotes awareness of renewable energy technologies among the public. As urban areas continue to expand, such innovative solutions become increasingly important for balancing energy needs with spatial and environmental constraints.

The solar tree concept represents a significant advancement in solar energy utilization by addressing the key challenges of space, efficiency, and design. It provides a promising pathway for integrating renewable energy systems into modern urban infrastructure while supporting the transition toward a more sustainable and energy-efficient future.

## 2. LITERATURE REVIEW

In[1] author analyzed various solar tree designs and highlighted their advantages over conventional solar

systems. Their study focuses on structural configurations that improve sunlight exposure and energy efficiency. The paper emphasizes the importance of optimized design in enhancing solar energy generation in limited spaces. In [2] author reviewed different solar tree models along with their performance and practical applications. The study discusses benefits such as space-saving and higher energy output, while also identifying challenges like cost and maintenance. It highlights the potential of solar trees in urban energy solutions. In [3] author explored the technological aspects and configurations of solar trees. Their work explains how innovative arrangements of panels improve efficiency and energy capture. The study also discusses recent advancements in solar tree technology and system integration. In [4] author proposed a design framework aimed at maximizing power output from solar trees. They analyzed factors such as panel orientation, tilt angle, and structural layout. Their findings show that optimized design significantly enhances energy generation. Detailed performance evaluation of solar tree systems under varying environmental conditions was conducted in [5]. The study compares efficiency, energy output, and reliability with traditional solar panels. Results indicate that solar trees are more effective in space-constrained environments. A solar tree system using an Arduino-based control mechanism was developed in [6]. Their work demonstrates the integration of sensors and microcontrollers for automation. The study highlights the feasibility of low-cost and smart solar energy solutions. In [7] author introduced a solar tree equipped with an automatic sun tracking system. The system uses sensors and motors to align panels with sunlight for improved efficiency. Their results show a significant increase in energy output compared to fixed systems. In [8] author proposed an IoT-enabled solar tracking system for enhanced monitoring and control. The system allows real-time data tracking and remote operation. Their research demonstrates improved performance and reliability using smart technologies. A comparative analysis between conventional solar panels and solar tree systems was conducted in [9]. Their study shows that solar trees generate more energy per unit area. It highlights the efficiency and space-saving advantages of solar tree technology. In [10] author focused on designing solar trees suitable for urban environments. Their work emphasizes compact structure, improved aesthetics, and efficient energy generation. The study concludes that solar trees are ideal for smart city applications and sustainable development.

### 3. METHODOLOGY

The methodology of the solar tree system focuses on the systematic design, development, and implementation of a compact and efficient solar energy generation model inspired by a tree-like structure. This approach integrates engineering design, component optimization, and performance evaluation to ensure improved energy efficiency within limited space. The methodology is divided into several stages, each addressing a specific aspect of system development and functionality.

#### 3.1 System Design

The initial stage involves the conceptualization and design of a tree-shaped structure using advanced 3D modeling techniques. The design mimics the natural arrangement of branches in a tree to optimize sunlight exposure. Multiple small photovoltaic (PV) panels are mounted on branches at varying heights and orientations. This multi-directional arrangement allows panels to capture sunlight from different angles throughout the day, thereby increasing overall energy absorption. Special attention is given to minimizing shading between panels, as even partial shading can significantly reduce efficiency. Additionally, the vertical design ensures efficient utilization of space, making the system suitable for urban and semi-urban environments where land is limited.

#### 3.2 Component Selection

The selection of components is a critical step to ensure system efficiency, affordability, and ease of implementation. The primary components include low-power PV modules, an Arduino Mega microcontroller, Light Dependent Resistors (LDRs), servo motors, a rechargeable battery, and a charge controller. The solar panels are chosen based on their efficiency and compatibility with small-scale applications. The Arduino Mega serves as the central processing unit, enabling automation and control of the tracking mechanism. LDR sensors are selected for their simplicity and effectiveness in detecting light intensity variations. Servo motors are used for precise movement and positioning of panels. The battery and charge controller ensure safe storage and regulation of generated energy. All components are selected with a focus on cost-effectiveness and reliability.

#### 3.3 Solar Tracking Mechanism

To enhance energy generation, a solar tracking mechanism is incorporated into the system. This mechanism relies on LDR sensors to detect the direction of maximum sunlight. Typically, two or more LDRs are positioned at different orientations on the structure. These sensors continuously measure light intensity and send analog signals to the Arduino Mega. The microcontroller processes the difference in light intensity between sensors and determines the optimal direction for maximum exposure. Based on this analysis, control signals are sent to servo motors, which adjust the angle of the solar panels accordingly. This dynamic adjustment ensures that the panels remain aligned with the sun throughout the day, significantly improving energy output compared to fixed installations.

#### 3.4 Electrical Configuration

Fig.1 Shows Block diagram of proposed Solar module system. The electrical configuration of the solar tree system is designed to ensure efficient energy generation, regulation, and storage. The solar panels are connected in series to increase the output voltage, typically up to approximately 16V. This configuration is suitable for charging batteries and powering low-voltage devices. The generated electrical energy is passed

through a charge controller, which regulates voltage and current to prevent overcharging or damage to the battery. The regulated energy is then stored in a rechargeable battery for later use. The stored energy can be utilized to power various loads such as LED lighting systems, mobile charging units, or small electronic devices, making the system practical for real-world applications.

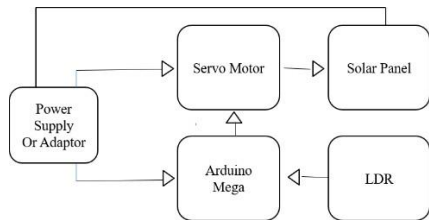


Fig 1. Block Diagram

### 3.5 Fabrication and Assembly

Proposed design of solar module is as shown in Fig.2 The fabrication stage involves constructing the physical

structure of the solar tree using lightweight and durable materials such as aluminum, plastic composites, or 3D-printed components. The use of 3D printing technology allows for precise and customizable designs, ensuring proper alignment and stability of the structure. Solar panels are carefully mounted on the branches, and wiring is arranged systematically to avoid energy losses and ensure safety. The integration of sensors, microcontroller, and servo motors is carried out with careful attention to connectivity and functionality. Proper insulation and protective measures are implemented to safeguard the system from environmental factors such as dust, moisture, and temperature variations.

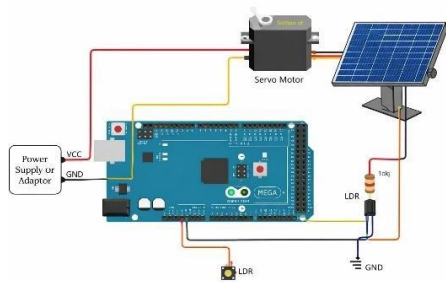


Fig.2 Circuit Diagram

### 3.6 Testing and Performance Evaluation

Specification of solar module is as follows. Once assembled, the solar tree system undergoes rigorous testing under various environmental conditions. Performance evaluation is conducted during different times of the day to assess energy generation under varying sunlight intensity. Key parameters such as output voltage, current, and overall efficiency are measured and recorded. The performance of the solar tracking system is also evaluated based on its response

time, accuracy, and ability to maintain optimal alignment with the sun. Comparative analysis is performed by testing a conventional fixed solar panel setup under similar conditions to determine the relative improvement in energy output.



Fig.3 Solar Module

### Specifications

- Solar Panel: 1W, 12–15V PV modules
- Microcontroller: Arduino Mega
- Sensors: LDR (Light Dependent Resistors)
- Actuator: Servo Motor (for tracking)
- Output Voltage: ~16V (series connection)
- Storage: Rechargeable battery with charge controller

### 3.7 Data Analysis

The final stage involves analyzing the collected data to evaluate the effectiveness of the solar tree system. Statistical and comparative methods are used to assess improvements in energy generation and efficiency. The results are compared with traditional flat-panel systems to validate the advantages of the solar tree design. Factors such as increased energy output per unit area, improved sunlight utilization, and system responsiveness are carefully examined. The analysis also helps identify potential areas for improvement, such as optimizing panel orientation, enhancing tracking algorithms, and reducing system losses.

Overall, the methodology provides a comprehensive framework for developing a solar tree system that is efficient, scalable, and suitable for modern energy needs, particularly in space-constrained environments.

#### 4. Discussion and Conclusion

Solar tree technology represents an innovative and efficient approach to harnessing solar energy, particularly in environments where space availability is limited. By integrating advanced structural design with renewable energy principles, the solar tree offers a unique alternative to conventional photovoltaic systems. Its vertical, tree-like configuration allows for optimal utilization of space while maximizing exposure to sunlight through strategically arranged panels. This makes it especially suitable for urban areas, public spaces, and smart city infrastructure where land constraints are a significant concern.

The incorporation of solar tracking mechanisms further enhances the efficiency of the system by ensuring that solar panels remain aligned with the sun throughout the day. This dynamic adjustment leads to improved energy generation compared to fixed-panel installations. Additionally, the use of compact and cost-effective components such as microcontrollers, sensors, and servo motors demonstrates the feasibility of implementing such systems on a small to medium scale. The ability to store generated energy and utilize it for practical applications, including lighting and charging devices, highlights the functional viability of solar trees in real-world scenarios.

In the context of sustainable development, solar trees hold significant potential as a decentralized energy solution. Their aesthetic appeal and multifunctional use make them ideal for integration into modern urban planning and smart city initiatives. As the demand for clean and renewable energy continues to grow, solar tree technology can contribute meaningfully to reducing dependence on fossil fuels and minimizing environmental impact.

While solar trees are still evolving, they offer a promising direction for the future of renewable energy systems. With continued innovation and supportive policy frameworks, they have the potential to become a key component in achieving sustainable and energy-efficient urban development.

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