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# Generation of Electric Power using Solar Panels above Railway Tracks

Vishal M. Kagge, Tejas M. J., Sunil J. V., Ashish P., Janardhan L. K.

U.G Student, Department of Electrical and Electronics Engineering, Channabasaveshwara Institute of Technology,  
Gubbi, Tumkur, Karnataka, India

Assistant Professor, Department of Electrical and Electronics Engineering, Channabasaveshwara Institute of  
Technology, Gubbi, Tumkur, Karnataka, India

**ABSTRACT:** "In response to the escalating global need for sustainable energy sources, this research delves into the potential of deploying solar photovoltaic systems directly above railway corridors to generate electricity. This approach seeks to transform previously overlooked railway spaces into valuable renewable energy assets. The investigation centers on a comprehensive analysis of the practical implementation, encompassing the design of optimized system architectures tailored to the unique characteristics of railway environments. It meticulously examines the economic viability, weighing the investment against projected energy yields and long-term cost-effectiveness, while also addressing the inherent technical challenges, such as vibration, electromagnetic interference, and grid integration. The study explores a spectrum of photovoltaic integration methodologies, ranging from overhead canopies to direct substation connections, evaluating their efficiency and compatibility with existing railway infrastructure. By leveraging sophisticated simulations and drawing upon real-world case studies from diverse international projects, the research aims to provide concrete evidence of the feasibility and effectiveness of this innovative energy generation strategy, demonstrating its potential to contribute significantly to the global renewable energy landscape."

## I. INTRODUCTION

"The imperative to transition away from finite fossil fuels and mitigate the escalating environmental impact of traditional energy generation has propelled a global movement towards sustainable alternatives. Among these, solar energy emerges as a particularly promising resource, given its widespread availability and renewable nature. In this context, existing railway infrastructure, which often traverses substantial land areas, presents a unique opportunity for large-scale solar photovoltaic (PV) deployment. This research explores the potential of strategically integrating PV systems directly above railway tracks, aiming to simultaneously augment renewable energy production and optimize the utilization of otherwise underutilized land. By leveraging the inherent linear expanse of railway corridors, this approach seeks to transform transportation networks into dual-purpose infrastructure, effectively contributing to both energy sustainability and land efficiency.

## II. LITERATURE REVIEW

"A range of scholarly investigations has delved into the application of solar energy within railway electrification and infrastructure expansion, highlighting diverse avenues for implementation. For instance, studies have examined the deployment of dynamic solar tracking mechanisms, demonstrating their capacity to enhance photovoltaic panel efficiency by continuously aligning with optimal sunlight angles. Comparative assessments of various photovoltaic integration designs within railway substations have also been conducted, aiming to refine power distribution and improve economic returns. Furthermore, researchers have investigated the installation of solar photovoltaic systems directly over railway lines, proposing a solution to mitigate land constraints while simultaneously reducing carbon footprints. Additionally, explorations into hybrid renewable energy systems, combining wind and solar technologies, have been undertaken to power critical railway components such as crossings and signaling networks. These research efforts collectively illustrate a growing interest in leveraging solar energy to advance the sustainability and efficiency of railway operations."



### III. SYSTEM DESIGN AND IMPLEMENTATION

#### 3.1 Structural Design:

"Implementing an elevated solar panel system over railway tracks necessitates a meticulously planned structural architecture. To guarantee unimpeded train operations, the solar arrays must be positioned roughly 10 meters above the rail lines. This clearance is vital for ensuring that neither train traffic nor routine track maintenance is hindered. The support system involves a sequence of reinforced concrete columns, strategically spaced at regular 5-meter intervals along the railway alignment. These columns establish a sturdy and enduring base for a modular platform system. This platform is engineered to streamline the installation and upkeep of the photovoltaic modules, enabling both expansion and flexibility. The use of concrete columns ensures a resilient structure capable of enduring environmental loads and the dynamic forces inherent in railway environments. Furthermore, the modular nature of the platform allows for adaptable solar panel configurations and simplifies future system enhancements or maintenance procedures. This design approach aims to provide a reliable, long-term solution that integrates solar energy generation with active rail infrastructure."

#### 3.2 Solar Panel Configurations:

└ **Fixed Solar Panels:** Static photovoltaic systems, the traditional method, involve securing solar panels at a constant, pre-calculated angle. This angle is generally determined by the site's geographical latitude, aiming to maximize annual solar energy absorption. Although they offer a straightforward and more economical setup, static systems may yield a reduced energy output compared to dynamic tracking systems. However, their simplicity and minimal maintenance requirements make them a dependable choice for regions with predictable solar irradiance."

- **Single-axis and Dual-axis Tracking Systems:** To optimize solar power production, dynamic tracking systems are implemented to adapt the angle of solar panels in accordance with the sun's trajectory. Single-axis trackers facilitate rotation along a singular plane, commonly east-west, to align with the sun's diurnal motion. Conversely, dual-axis trackers offer movement across both horizontal and vertical planes, enabling precise alignment with the sun's location throughout the day and across varying seasons. These systems can substantially boost energy efficiency, with research indicating potential enhancements of 30-60% relative to static installations. This heightened energy yield stems from the panels' capacity to maintain a perpendicular alignment to incident sunlight, thereby maximizing solar irradiance capture. Nevertheless, tracking systems introduce increased complexity and necessitate greater upfront capital and continuous upkeep.

#### 3.3 Energy Conversion and Storage:

To effectively harness and manage solar energy from photovoltaic (PV) arrays for grid integration and a stable power supply, several key technologies are employed. First, Maximum Power Point Tracking (MPPT) techniques are fundamental. These algorithms function by constantly monitoring the PV array's voltage and current, dynamically adjusting the operating point to extract the highest possible power output under fluctuating irradiance levels. This optimization is critical for maximizing energy harvest and ensuring peak efficiency.

Following this, DC-DC boost converters are utilized to increase the direct current (DC) voltage from the PV system. This voltage amplification is essential for minimizing transmission losses over longer distances and achieving compatibility with grid connection standards. The boosted DC voltage facilitates efficient power transfer to the grid or to subsequent energy storage systems.

Furthermore, battery energy storage systems (BESS) are incorporated to provide a consistent and dependable power supply. These systems store excess solar energy produced during periods of high insolation, enabling power delivery during periods of low or no sunlight, such as during nighttime or cloudy conditions. This storage capability helps to smooth out the inherent intermittency of solar energy, enhancing grid stability.

Finally, seamless grid integration is vital for distributing surplus energy to the broader electrical network. This interconnection ensures that the generated solar power is effectively utilized, contributing to grid reliability and stability. Moreover, it allows for potential revenue generation through the sale of excess power back to the grid, incentivizing further deployment of solar energy systems.

### 3.4 Working

This model demonstrates a solar energy system that incorporates both automatic solar tracking and voltage monitoring for enhanced efficiency. At its core is an **Arduino Nano microcontroller**, which coordinates input from sensors, directs a servo motor to adjust the panel's orientation, and displays vital data through an LCD interface. The setup employs a **solar panel** to harness sunlight and convert it into electrical energy. Mounted with **Light Dependent Resistors (LDRs)** on either side, the panel can detect the variation in sunlight intensity. These LDRs act as light sensors, sending analog signals to the Arduino, which calculates which direction receives more light.

Based on the LDR input, the **servo motor** is instructed to reposition the solar panel to face the direction of highest light intensity. This dynamic tracking mechanism helps to maximize exposure to sunlight throughout the day, significantly increasing power generation efficiency compared to a fixed panel system.

The electricity generated is routed through a **diode**, ensuring one-way current flow to prevent battery discharge at night. The current then moves through a **voltage booster**, which amplifies it to a level suitable for **charging the battery**. This stored energy can then be used to power devices or systems when sunlight is unavailable.

To ensure the system's performance is continuously tracked, a **voltage sensor** is linked to the battery. This sensor measures the battery's voltage level and communicates the data to the microcontroller for real-time analysis. Information such as **voltage levels and system status** is then presented on the **LCD display**. This allows users to monitor the energy system's behavior at a glance, improving system transparency and management.

Overall, the **Arduino Nano** serves as the brain of the model, processing sensor inputs, executing tracking algorithms, and updating the display. The integration of these components provides an intelligent solution for solar power generation and monitoring, suitable for smart energy applications. All these can be seen connected using circuit in the fig 3.1

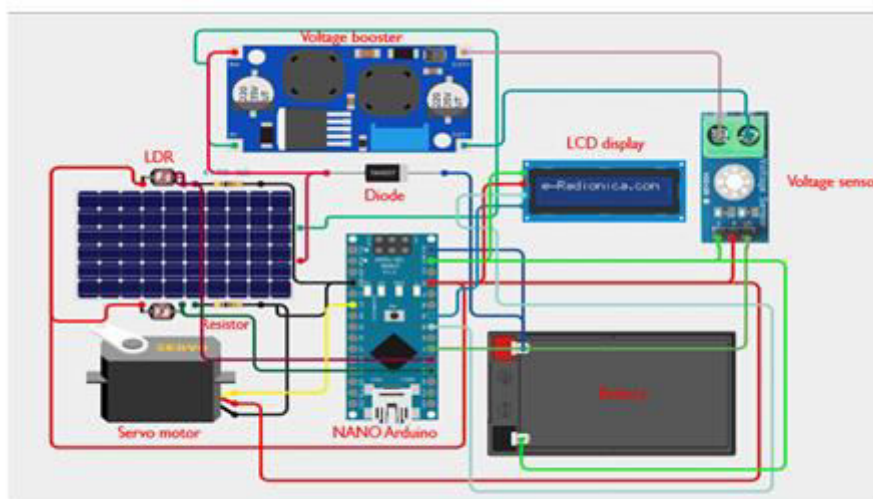


Fig 3.1 The Circuit Diagram of the model.

## IV. ENERGY GENERATION AND FEASIBILITY ANALYSIS

### 4.1 Case Study Simulations:

In the Rangpur region of Bangladesh, a practical application showcases the potential of implementing solar photovoltaic (PV) arrays over railway lines. This initiative involved installing a large-scale system, consisting of 180,366 solar panels, strategically placed above the existing rail infrastructure. The system's annual energy output reached 102,230,040 kWh, highlighting the considerable energy production achievable in areas with ample sunlight. Moreover, the project's financial viability was demonstrated by a Levelized Cost of Energy (LCOE) of 7.77 US cents

per kWh, suggesting a cost-effective alternative to conventional energy sources. The project's overall investment was estimated at \$90.24 million. However, its economic sustainability was supported by a projected 10-year payback period, indicating long-term financial benefits and investment returns. This real-world example effectively illustrates how solar PV systems integrated with railway infrastructure can provide substantial renewable energy generation, all while maintaining a strong economic foundation.

#### 4.2 Economic Considerations:

Integrating solar photovoltaic (PV) systems into railway infrastructure involves a significant initial financial outlay, demanding a thorough evaluation of long-term economic gains. The substantial upfront costs, encompassing materials, installation, and grid connection, are balanced by the operational savings achieved throughout the system's lifespan. Furthermore, governmental incentives and subsidies, aimed at accelerating the adoption of renewable energy sources, play a crucial role in enhancing the project's financial feasibility. A comprehensive cost-benefit analysis is essential, incorporating the projected long-term energy production and the reduction in ongoing operational expenses.

Beyond the economic aspects, the environmental advantages are of utmost importance. Transitioning from fossil fuel-based energy to solar power leads to a notable decrease in carbon dioxide (CO<sub>2</sub>) emissions, supporting global initiatives to combat climate change and promote ecological sustainability. This reduced dependence on fossil fuels also strengthens energy autonomy and minimizes exposure to volatile fuel prices.

Moreover, the development and maintenance of these solar installations create valuable employment opportunities. The construction phase requires a skilled labor force for installation and electrical work, while continuous maintenance and monitoring generate sustained employment within the renewable energy sector, contributing to local economies and facilitating a shift towards a sustainable workforce.

### V. INTEGRATION WITH RAILWAY INFRASTRUCTURE

#### 5.1 Power Distribution and Utilization:

Integrating solar photovoltaic (PV) systems into railway infrastructures unlocks various pathways for sustainable energy management and operational efficiency. One primary application involves direct electrification of railway lines, where solar-derived power directly fuels electric train traction. This strategy lessens dependence on conventional grid electricity, which often relies on fossil fuels, thereby significantly reducing the railway's carbon emissions.

Furthermore, leveraging grid interconnection allows for the seamless transfer of surplus solar energy into the national power grid. When solar irradiance peaks, the PV system may generate more energy than the railway network requires. This excess can be exported to the grid, supplementing the overall energy supply and potentially creating a new revenue stream for the railway company.

Crucially, the integration of energy storage solutions ensures a consistent and reliable power supply, particularly during periods of low solar radiation or nighttime. Storage systems like batteries and ultracapacitors are employed to store excess energy generated during daylight. Batteries offer long-term energy storage, suitable for overnight power requirements, while ultracapacitors provide rapid charge and discharge capabilities, ideal for handling short-term fluctuations in energy demand. These storage solutions enhance system robustness, enabling a continuous and stable power flow irrespective of weather conditions or time of day, and allow for better management of power demand and supply.

#### 5.2 Challenges and Solutions:

Deploying solar photovoltaic (PV) arrays over railway tracks offers a sustainable energy solution, but it necessitates addressing several practical hurdles. One key issue is the buildup of particulates on the solar panels, which drastically diminishes their ability to generate electricity. To counteract this, the integration of self-operating robotic cleaning mechanisms is suggested. These systems would independently traverse the panel layout, systematically eliminating dust and detritus at consistent intervals, thereby sustaining peak efficiency and maximizing power production.

Ensuring safety is paramount in any installation near railway infrastructure. The incorporation of strong protective shields is vital to prevent accidental interaction with live electrical components and to protect railway workers and the

general public. Scheduled upkeep procedures, including inspections and repairs, are crucial for guaranteeing the system's ongoing safety and dependability.

Furthermore, the influence of fluctuating weather conditions presents a considerable obstacle. Solar panels must be constructed to endure a wide spectrum of environmental pressures, encompassing rainfall, snowfall, and extreme temperature variations. The use of hydrophobic coatings and the fine-tuning of panel inclinations can mitigate the effects of precipitation and facilitate effective drainage, preventing moisture-related damage and maintaining operational efficiency. Moreover, a meticulous evaluation of local weather patterns during the planning phase is indispensable for selecting suitable materials and configurations that can withstand the unique climatic challenges of the installation location.

## **VI. FUTURE PROSPECTS AND RECOMMENDATIONS**

The future of integrating solar photovoltaic (PV) systems into railway infrastructure is bright, but hinges on strategy c planning and technological progress. A pivotal advancement is the deployment of intelligent monitoring systems. Utilizing artificial intelligence (AI), these systems can provide real-time performance tracking of solar panels, detect deviations from expected efficiency, and enable predictive maintenance. This results in enhanced energy output and lower operational expenses.

Moreover, investigating hybrid renewable energy models presents a valuable method for maximizing energy yield. By combining wind turbines with solar panels, especially in areas with favorable wind conditions, a more stable and dependable energy source can be established, addressing the inherent variability of solar energy. This blended approach diversifies energy inputs and bolsters overall system robustness.

For widespread global implementation, well-defined policy recommendations are vital. Governments should introduce incentive schemes, like tax benefits and feed-in tariffs, to stimulate private sector investment in solar railway projects. Furthermore, simplified regulatory procedures and standardized grid interconnection protocols would accelerate project development and deployment. International partnerships and knowledge exchange programs are also essential for sharing best practices and promoting a global shift towards sustainable railway energy solutions. All these can be seen in the fig 6.1.



**Fig 6.1 Model**

## **VII. CONCLUSION**

Harnessing the potential of solar photovoltaic (PV) systems positioned over existing railway lines presents a compelling strategy for large-scale renewable energy production. This methodology effectively leverages otherwise underutilized railway rights-of-way, providing a distinctive avenue to substantially increase sustainable energy output.



Key to the success of these ventures are: rigorous structural engineering, ensuring seamless railway functionality; and the deployment of efficient power conversion systems that maximize energy capture and facilitate seamless grid integration. Furthermore, incorporating optimized energy storage, notably advanced battery technologies, is essential for maintaining a stable and dependable power supply, addressing the inherent variability of solar energy. As PV technology continues to advance, with improvements in panel efficiency and longevity, the practicality and economic attractiveness of these installations will be further enhanced. Facilitating widespread adoption necessitates robust policy initiatives, including governmental incentives and simplified regulatory procedures. This dual approach not only bolsters the global shift towards a sustainable energy paradigm but also transforms railway infrastructure into a valuable asset for renewable energy generation.

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