# Hybrid Regenerative EV Charging System

**Bhagat Rutuja Shivaji[1], Tambat Sanika Suryakant[2], Vishwase Rutuja Anil[3]**

[1,2,3]Matoshri college of engineerin and research centre, Nashik

**Abstract:**
This project presents the design and development of a regenerative braking system using a Brushless DC (BLDC) motor, controlled by an Electronic Speed Controller (ESC) and an Arduino Nano microcontroller. The main objective of this system is to improve energy efficiency by recovering energy that is normally lost during braking and converting it into usable electrical energy.The system is designed to operate in two main modes: normal motor mode and regenerative braking mode. In the normal mode, the BLDC motor operates as a conventional motor. The Arduino Nano generates Pulse Width Modulation (PWM) signals which are provided to the ESC. Based on these signals, the ESC controls the speed and operation of the BLDC motor by supplying appropriate three-phase voltage. This allows smooth and efficient motor operation for performing mechanical work.When braking is required, the system switches to regenerative mode. In this mode, the Arduino Nano first reduces the speed of the motor gradually to ensure safe operation and avoid sudden damage to components. After reducing the speed, the system uses a relay-based switching mechanism to disconnect the ESC from the motor and connect the motor terminals to a three-phase bridge rectifier.

## 1.Introduction

During regenerative braking, the BLDC motor acts as a generator. The kinetic energy of the rotating motor is converted into electrical energy in the form of three-phase AC supply. This generated AC power is then converted into DC using the bridge rectifier. The converted DC energy can either be stored in a battery or used for other low-power applications, thereby improving overall system efficiency.The Arduino Nano plays a crucial role in controlling the entire process. It manages PWM signal generation, relay switching, and mode selection through a push button interface. The inclusion of an LED indicator helps in displaying the current mode of operation, making the system user-friendly.
This project demonstrates a basic yet effective implementation of regenerative braking, which is widely used in modern electric vehicles and energy-efficient systems. By recovering energy during braking, the system reduces energy loss, increases efficiency, and contributes to sustainable energy utilization.Overall, this project provides a practical understanding of motor control, power electronics, and energy recovery techniques. It also highlights the importance of integrating hardware and software to develop efficient and smart systems for real-world applications

### 1.1 Literature Survey

A Hybrid Regenerative EV Charging System is designed to improve the charging efficiency and performance of electric vehicles by combining regenerative braking and solar energy harvesting. The system recovers kinetic energy from the vehicle’s wheel rotation and braking process using a BLDC motor, which acts as a generator to produce electrical energy that is stored in the battery through a charge controller. Along with this, a 10W solar panel continuously provides supplementary charging, especially when the vehicle is idle or running under sunlight. The Arduino Nano is used to monitor the voltage and current levels from both regenerative and solar sources and measure using multimeter. This hybrid setup ensures that the battery is charged from multiple renewable sources, thus extending the vehicle’s running time and reducing dependence on external power supply. The combination of solar and regenerative energy makes the system highly efficient, cost-effective, and environmentally friendly, making it suitable for future sustainable transportation systems. Similar research work on regenerative braking with solar hybrid systems for electric vehicles has been presented in [1], which supports the feasibility and importance of integrating both energy recovery and solar charging methods in modern EVs.

The concept of regenerative charging plays a major role in improving the performance and efficiency of electric vehicles by converting mechanical energy into electrical energy during motion and braking. In this project, the Hybrid Regenerative EV Charging System follows the same principle explained in [2], where the kinetic energy generated by the rotating wheels is captured through a BLDC motor working as a generator. The generated power is directed to the battery via a regulated charging circuit, ensuring stable voltage and current flow. This regenerative technique allows continuous battery charging without external power when the vehicle is in motion. To enhance the charging process further, a solar panel is integrated to provide hybrid support, making the system more sustainable and energy-efficient. The Arduino Nano continuously monitors charging parameters like voltage, current, and battery level, display. By combining regenerative braking and solar charging, this system not only reduces overall energy losses but also increases the driving range of electric vehicles. Thus, the hybrid regenerative approach demonstrated in this project successfully extends the idea presented in [2] by implementing both energy recovery and renewable solar integration for a more efficient EV charging system.

The control and monitoring of hybrid energy systems require smart and efficient microcontroller-based technology to manage multiple charging sources. In this project, the Arduino Nano is used as the central control unit for handling regenerative and solar charging processes, similar to the smart solar charging system presented in [3] . The Arduino Nano efficiently monitors input voltage and current from both the regenerative BLDC motor generator and the solar panel, processes the data. It also helps in maintaining balanced charging by regulating the flow of current through a charge controller circuit, preventing overcharging and ensuring battery protection. The system can be programmed to give priority to regenerative energy when the vehicle is in motion and switch to solar energy when it is stationary or under sunlight.

The research presented in [4] focuses on developing a regenerative braking system controlled by the Arduino Nano to enhance energy recovery efficiency in electric vehicles. Based on the same concept, this project applies the regenerative charging principle to capture the kinetic energy generated during vehicle motion and braking through a BLDC motor acting as a generator. The generated energy is then directed through a voltage sensor and regulated by a charge controller before storing it in the battery. The Arduino Nano is used as the main control unit to monitor voltage and current parameters and to manage the charging flow from both regenerative and solar inputs. By combining regenerative energy recovery with solar charging, the system achieves higher efficiency and reduces dependency on external charging sources. The study in [4] supports the practical implementation of such energy recovery mechanisms using modern microcontrollers, aligning well with the objective of this Hybrid Regenerative EV Charging System to improve battery performance and promote sustainable energy utilization in electric vehicles.

The study in [5] emphasizes the importance of regenerative braking and effective battery management in improving the charging efficiency and overall performance of electric vehicles. The same concept is implemented through a Hybrid Regenerative EV Charging System that combines regenerative energy recovery with solar charging support. When the vehicle moves or brakes, the BLDC motor operates as a generator and converts mechanical energy into electrical power, which is then supplied to the battery through a controlled charging circuit. The Arduino Nano monitors and regulates the charging parameters, ensuring stable voltage and current flow to protect the battery. The inclusion of a 10W solar panel provides an additional renewable energy source, allowing hybrid operation and reducing external power dependency. This combination of regenerative braking and proper charge management increases system reliability and extends battery life. The approach discussed in [5] directly aligns with the project’s objective of enhancing energy utilization, improving charging efficiency, and promoting sustainable power systems for electric vehicles through the integration of hybrid energy recovery and smart control techniques.

The research presented in [6] focuses on the development of a solar electric vehicle with multiple charging systems, showing how combining different renewable energy sources can significantly enhance overall efficiency. Based on this concept, the proposed Hybrid Regenerative EV Charging System integrates three main energy sources solar panel, wheel rotation, and braking energy to achieve continuous and self-sustained charging. When the vehicle is in motion, the wheel rotation drives a BLDC motor that acts as a generator, converting mechanical energy into electrical energy. During braking, additional kinetic energy that would otherwise be wasted as heat is recovered and sent back to the battery through a charge controller. Simultaneously, the solar panel provides continuous charging support, especially under sunlight conditions, ensuring that the battery is maintained even when the vehicle is idle. The Arduino Nano monitors and manages the energy flow from all three sources. The study in [6] directly supports this hybrid approach, proving that the combination of solar, wheel rotation, and braking-based charging systems can greatly improve energy recovery, reduce power loss, and extend the operating range of electric vehicles.

The study presented in [7] highlights the use of a DC/DC buck-boost converter in regenerative braking systems to effectively control and stabilize the voltage generated during energy recovery. The same principle is applied to the Hybrid Regenerative EV Charging System to ensure efficient conversion and charging of the battery from multiple energy sources braking, wheel rotation, and solar panel. During braking and wheel rotation, the BLDC motor functions as a generator, producing variable voltage levels depending on the speed and load. The buck-boost converter circuit maintains a steady output voltage, ensuring the battery receives stable and efficient charging without overvoltage or energy loss. The solar panel simultaneously provides additional power, contributing to hybrid charging operation. The Arduino Nano continuously monitors the voltage and current from all sources and manages charging through control algorithms. The concept described in [7] supports the hardware design of this project by providing an efficient power regulation technique for regenerative systems, improving battery life, charging stability, and the overall energy efficiency of hybrid electric vehicles.

The project described in [8] focuses on managing electric vehicle charging through solar energy using an advanced control system known as Solar EVSE. Inspired by this concept, the proposed Hybrid Regenerative EV Charging System incorporates a similar approach by combining solar energy, braking energy, and wheel rotation energy to achieve continuous and efficient hybrid charging. The solar panel provides steady charging when sunlight is available, while regenerative braking and wheel rotation convert mechanical motion into electrical power through a BLDC motor operating as a generator. These multiple energy sources are regulated and monitored using the Arduino Nano, which manages the charging process and ensures optimal battery performance. The system uses a charge controller and voltage sensor to protect the battery from overcharging and voltage fluctuations. The methodology discussed in [8] supports the solar-based control and management aspect of this project, making it more reliable, smart, and energy-efficient. By integrating solar, braking, and wheel rotation inputs, the system demonstrates an advanced hybrid model capable of maintaining battery charge and reducing dependence on external power supplies.

### 1.2 Problem Statement

In conventional motor-driven systems and vehicles, a significant amount of energy is lost during the braking process. When a motor or vehicle slows down, its kinetic energy is typically converted into heat due to friction and is dissipated into the environment. This results in poor energy utilization and reduced overall system efficiency. With the increasing demand for energy conservation and sustainable technologies, minimizing such energy losses has become a critical challenge in modern engineering systems.

Although regenerative braking systems are widely used in electric vehicles and advanced industrial applications, their implementation often involves complex and expensive hardware, making them less accessible for small-scale applications and educational purposes. There is a need to develop a simple, cost-effective, and easy-to-understand system that can demonstrate the concept of regenerative braking and energy recovery using basic components.

Another challenge lies in controlling the BLDC motor efficiently while ensuring smooth transition between motor operation and generator operation. Improper switching between these modes can lead to system instability, electrical damage, or mechanical stress. Therefore, it is necessary to design a reliable control mechanism that can safely manage the switching process and maintain system performance.

Additionally, the conversion of generated electrical energy into a usable form is an important concern. The electrical energy produced during regenerative braking is in the form of AC, which needs to be converted into DC for storage or utilization. Ensuring efficient energy conversion and proper interfacing between components is essential for the successful implementation of the system.

Hence, the problem addressed in this project is to design and develop a compact, low-cost regenerative braking system using a BLDC motor, Arduino Nano, and relay-based switching, which can effectively control motor operation, enable safe mode switching, and recover energy during braking in a usable form. The system should be simple enough for educational use while demonstrating the fundamental working principle of regenerative braking used in real-world applications.

### 1.3 Objective

The main objective of this project is to design and develop a **regenerative braking system using a BLDC motor**, controlled by an **Arduino Nano and Electronic Speed Controller (ESC)**. The system aims to demonstrate how energy that is normally lost during braking can be recovered and converted into useful electrical energy. By implementing this concept on a small scale, the project provides a clear understanding of energy-efficient technologies used in modern applications such as electric vehicles and smart systems.

One of the primary objectives is to **control the speed and operation of a BLDC motor using PWM signals** generated by the Arduino Nano. This involves interfacing the Arduino with the ESC and ensuring smooth motor operation under different conditions. The project aims to achieve stable and efficient motor control by varying the PWM signal, which directly influences the motor speed. This helps in understanding the working of motor control systems and the role of microcontrollers in automation.

Another important objective is to **implement dual functionality of the BLDC motor**, where it operates both as a motor and as a generator. In normal mode, the motor converts electrical energy into mechanical energy, while in regenerative braking mode, it converts mechanical energy back into electrical energy. This dual operation highlights the principle of energy conversion and demonstrates how a single device can perform multiple functions depending on the system configuration.

The project also aims to **develop a relay-based switching mechanism** that allows safe and efficient transition between motor mode and regenerative braking mode. The relays are controlled by the Arduino Nano and are used to switch the connections of the motor between the ESC and the bridge rectifier. Ensuring smooth and safe switching is a key objective, as improper switching can damage the system components. Therefore, the system is designed to reduce motor speed before switching, improving reliability and safety.

Another objective is to **convert the generated AC power into usable DC power** using a bridge rectifier. During regenerative braking, the BLDC motor generates three-phase AC voltage, which needs to be converted into DC for storage or utilization. This part of the project focuses on understanding power conversion techniques and the importance of rectification in electrical systems.

The project further aims to **provide a simple user interface using a push button switch** for mode selection. This allows the user to manually control the operation of the system and switch between normal mode and braking mode. Additionally, an LED indicator is used to display the current mode of operation, making the system easy to monitor and operate.

Another key objective is to **demonstrate the concept of energy recovery and efficiency improvement**. By capturing the energy that would otherwise be lost during braking, the system shows how overall efficiency can be increased. This objective aligns with the growing need for sustainable and energy-efficient technologies in modern engineering.

The project also focuses on **developing practical skills in embedded systems and power electronics**. It involves programming the Arduino Nano, interfacing various hardware components, and ensuring proper system integration. This hands-on experience helps in bridging the gap between theoretical knowledge and practical implementation, which is essential for engineering students.

Finally, the project aims to **create a low-cost, compact, and easy-to-understand prototype** that can be used for educational purposes. The system is designed using readily available components, making it accessible for students and beginners. It serves as a basic model to understand the working of regenerative braking systems used in real-world applications.

In conclusion, the objectives of this project are centered around motor control, energy recovery, system integration, and practical learning. By achieving these objectives, the project successfully demonstrates the importance of efficient energy utilization and provides a foundation for further advancements in regenerative braking technology.

## 2. System Development

### 2.1 Block Diagram:

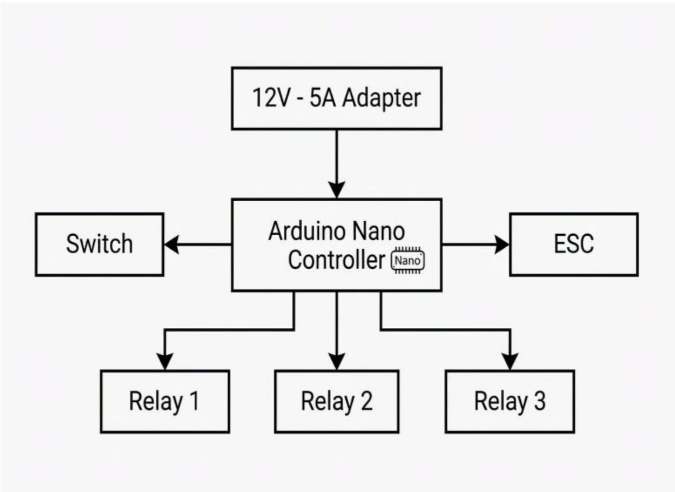



**Fig 2.1 : Block Diagram**

### 2.2 Block Diagram Description:

**1. Power Supply (12V – 5A Adapter / Battery)**

The power supply block provides the required electrical energy to operate the entire system. In this project, a 12V–5A adapter or a battery (Li-ion/LiPo) is used. This supply powers the Arduino Nano, ESC, and relay modules. The ESC requires sufficient current to drive the BLDC motor, while the Arduino operates at a regulated 5V level. A stable power supply is very important to ensure proper functioning, avoid voltage fluctuations, and maintain system reliability during both motor operation and braking mode.

**2. Arduino Nano Controller**

The Arduino Nano acts as the central control unit of the system. It is based on the ATmega328P microcontroller and operates at 5V. It is responsible for controlling all system operations. The Arduino reads input from the push button switch and decides whether the system should operate in motor mode or regenerative braking mode. It generates PWM (Pulse Width Modulation) signals to control the ESC and motor speed. It also controls the relay modules to switch connections between the ESC and the rectifier. Thus, the Arduino ensures proper coordination between all components and enables smooth and safe operation.

**3. Push Button Switch**

The push button switch is used as a user input device. It allows the user to control the mode of operation of the system. When the button is pressed, the Arduino detects the signal and initiates the switching process from motor mode to braking mode. When the button is not pressed, the system continues in normal operation. This simple interface makes the system easy to operate and provides manual control over mode selection.

**4. Electronic Speed Controller (ESC)**

The ESC is an important component used to control the BLDC motor. It receives PWM signals from the Arduino Nano and converts the DC input power into a controlled three-phase AC output. This three-phase supply is required to drive the BLDC motor. The ESC controls the speed, direction, and smooth operation of the motor based on the PWM signal. It ensures efficient power conversion and provides protection features like smooth start and stop. In motor mode, the ESC is directly connected to the motor through relays.

**5. Relay Module (Relay 1, Relay 2, Relay 3)**

The relay module consists of three relays, each corresponding to one phase of the BLDC motor. These relays act as switches that control the connection of the motor. In normal mode, the relays connect the motor to the ESC, allowing it to operate as a motor. In regenerative braking mode, the relays disconnect the ESC and connect the motor to the bridge rectifier. The Arduino controls the relays by sending signals to switch their state. This switching mechanism is essential for changing the mode of operation safely and effectively.

**6. BLDC Motor**

The BLDC (Brushless DC) motor is the main electromechanical component of the system. It operates in two modes. In motor mode, it receives three-phase power from the ESC and converts electrical energy into mechanical energy, causing rotation. In regenerative braking mode, the same motor acts as a generator. The rotational motion of the motor produces electrical energy in the form of three-phase AC voltage. This dual functionality makes the BLDC motor suitable for regenerative systems.

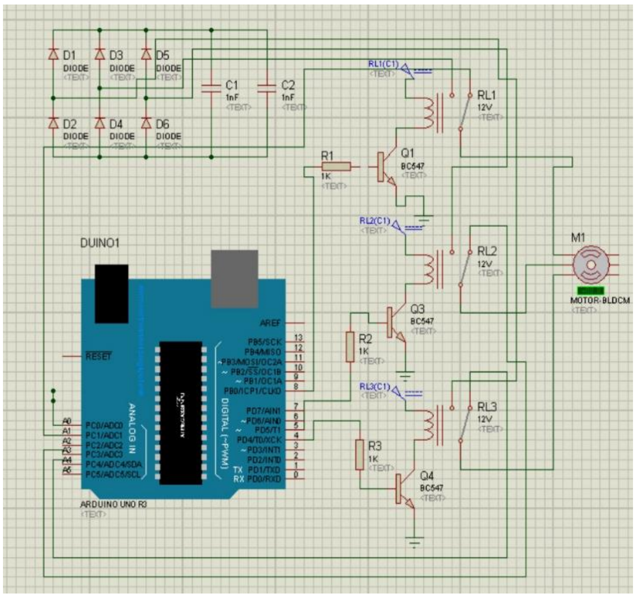
**7. Bridge Rectifier (3-Phase)**

The bridge rectifier is used during regenerative braking mode. It converts the three-phase AC voltage generated by the BLDC motor into DC voltage. This conversion is necessary because most storage devices and electronic circuits require DC power. The rectifier ensures that the output is unidirectional and can be used effectively. The converted DC energy can be stored in a battery or used for other purposes, improving overall system efficiency.

**8. LED Indicator**

The LED indicator is used to display the status of the system. It helps the user identify whether the system is operating in motor mode or regenerative braking mode. For example, the LED may glow in motor mode and turn off or change state in braking mode. This visual indication improves usability and helps in monitoring system operation.

**2.3 Circuit Diagram:**




## 3. Result and Conclusion

### 3.1 Result:

The regenerative braking system using a BLDC motor, Arduino Nano, and ESC was successfully designed and implemented. The system operated effectively in both **motor mode** and **regenerative braking mode** as intended.

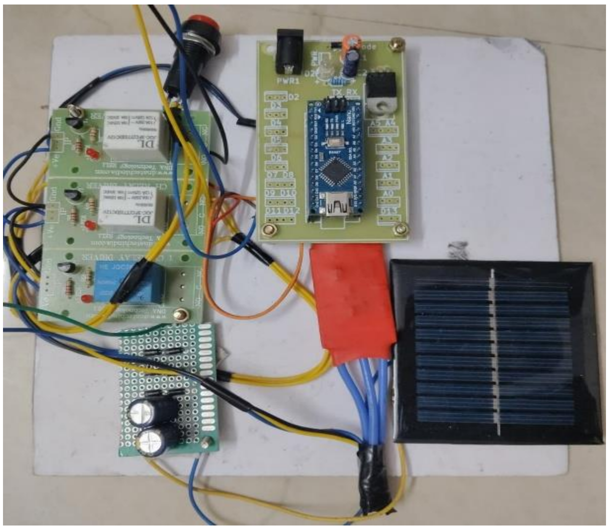
In motor mode, the Arduino Nano generated PWM signals that were supplied to the ESC, enabling smooth and controlled operation of the BLDC motor. The motor responded correctly to speed variations, demonstrating proper coordination between the controller and the ESC.

During regenerative braking mode, the system successfully switched from motor operation to generator operation using relay modules. The Arduino ensured safe switching by reducing the motor speed before activating the relays. Once switched, the BLDC motor acted as a generator and produced three-phase AC power.

This generated AC power was successfully converted into DC using a bridge rectifier. The output confirmed that energy was recovered during braking instead of being wasted. The LED indicator correctly displayed the system mode, and the push button allowed smooth toggling between modes.

Testing results showed:

- Proper functioning of relay switching mechanism
- Smooth transition between motor and braking modes
- Successful energy conversion from mechanical to electrical form
- Stable system performance under normal operating conditions



**3.2 Conclusion:**

The project successfully demonstrates the concept of **regenerative braking using a BLDC motor** in a simple and cost-effective way. It proves that energy, which is normally lost during braking, can be recovered and reused, thereby improving overall system efficiency.

The use of Arduino Nano makes the system flexible and easy to control, while the relay-based switching mechanism provides a simple method to alternate between motor and generator modes. Although this is a basic prototype, it effectively represents the working principle used in real-world electric vehicles and energy-efficient systems. This project provides a strong understanding of motor control, embedded systems, and power electronics. It also highlights the importance of energy conservation and sustainable technology in modern engineering applications. In future, the system can be improved by replacing relays with solid-state switching devices, adding battery storage for recovered energy, and enhancing efficiency for real-time applications. Overall, the project is successful in achieving its objective of demonstrating a functional regenerative braking system with dual operation of a BLDC motor as both a motor and a generator.

**REFERENCES:**

1. R. Patel and A. Sharma, “Regenerative Braking with Solar Hybrid System for Electric Vehicles,” ResearchGate, Aug. 2025. [Online]. Available: https://www.researchgate.net/publication/Regenerative-Braking-with-Solar-Hybrid-System-for-EV

2. Kumar, “Regenerative Charging Technique for Electrical Vehicles,” International Journal of Recent Technology and Engineering (IJRTE), vol. 12, no. 3, pp. 45–49, 2023. [Online]. Available: https://www.ijrte.org/papers/regenerative-charging-technique-for-evs.pdf
3. S. Bhagat, “Enhancing EV Charging Efficiency Through Regenerative Braking and Battery Management Systems,” International Journal of Scientific Research in Engineering and Management (IJSREM), vol. 9, no. 5, pp. 110–116, 2025. [Online]. Available: https://ijsrem.com/regenerative-braking-bms-evs
4. N. Singh et al., “Design and Development of Solar Electric Vehicle with Four Different Charging Systems,” International Journal of Applied Engineering and Management (IJAEM), Sept. 2022. [Online]. Available: https://www.ijaem.net/issue/solar-ev-multi-charging.pdf
5. R. C. Dugan, “Regenerative Braking System Using DC/DC Buck-Boost Converter,” River Publishers, pp. 201–208, 2020. [Online]. Available: https://www.riverpublishers.com/book_chapter/regenerative-braking-dcdc-converter
6. T. Edwards, “Solar EVSE: Manage Electric Vehicle Charging with Solar Power,” GitHub Project, 2024. [Online]. Available: https://github.com/solarevse/Solar-EVSE
7. P. Bastida-Molina, E. Hurtado-Pérez, M. C. Moros Gómez, and C. Vargas-Salgado, “Multicriteria Design and Experimental Verification of Hybrid Renewable Energy Systems: Application to Electric Vehicle Charging Stations,” arXiv Preprint, Mar. 2021. [Online]. Available: https://arxiv.org/abs/2103.16976
8. Y. Kumar et al., “Intelligent Energy Optimization of Parallel Hybrid Vehicles: Control and Monitoring Approach for Regenerative Braking Systems and Solar Panels,” Preprints.org, Jan. 2025. [Online]. Available: https://www.preprints.org/manuscript/202501.1253/v1
9. J. Y. Lee and K. Nam, “Energy Management and Control of Electric Vehicles Using Hybrid Power Source in Regenerative Braking Operation,” Energies, vol. 7, no. 7, pp. 4300–4316, 2014. [Online]. Available: https://www.mdpi.com/1996-1073/7/7/4300
10. S. S. Anitha, “Efficiency Analysis of Hybrid Extreme Regenerative System with Supercapacitor Battery and Vibration Energy Harvesting for Electric Vehicles,” Vehicles, vol. 15, no. 5, pp. 214–221, 2022. [Online]. Available: https://www.mdpi.com/2032-6653/15/5/214
11. Jain and P. Mehta, “Solar Wireless Electrical Vehicle Charging System,” International Journal for Research in Applied Science and Engineering Technology (IJRASET), May 2024. [Online]. Available: https://www.ijraset.com/research-paper/solar-wireless-electrical-vehicle-charging-system
12. S. Vejendla and P. Sowmithri, “Wireless Charging System for Electric Vehicle,” i-manager’s Journal on Embedded Systems, vol. 12, no. 1, pp. 9–15, 2023. [Online]. Available: https://imanagerpublications.com/viewarticles/12/1443/JESVol12Iss1
13. R. Patil et al., “Development of Solar-Based Electric Vehicle Charging Station,” International Journal of Engineering Research & Technology (IJERT), 2024. [Online]. Available: https://www.ijert.org/development-of-solar-based-electric-vehicle-charging-station
14. Patent WO2024263226A1, “Powering and Recharging Long-Range Electric Vehicles,” World Intellectual Property Organization (WIPO), 2024. [Online]. Available: https://patents.google.com/patent/WO2024263226A1/en