# ELECTRIC VEHICLE TECHNOLOGIES:
## TRENDS, CONTROL, AND CHARGING SOLUTIONS


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# Electric Vehicle Technologies: Trends, Control, and Charging Solutions

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**Electric Vehicle Technologies: Trends, Control, and Charging Solutions**

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# FOREWORD

The transition to Electric Vehicles (EVs) represents one of the most significant shifts in modern transportation, driven by the urgent need to reduce carbon emissions and reliance on fossil fuels. As governments and industries across the globe strive to address climate change and promote sustainable mobility, innovative technologies have become essential to the development and success of EVs. This collection of chapters delves into the core areas of research and development that are poised to shape the future of electric vehicles. From solar energy integration to advanced control systems, these chapters provide a comprehensive and forward-thinking perspective on the technologies that will drive the next generation of electric mobility.

Chapter 1, "A Review of Emerging Research Trends and Opportunities in Harnessing Solar Energy for Electric Vehicles," explores the growing importance of solar energy as a sustainable power source for EVs. This chapter presents an overview of the promising opportunities and challenges involved in integrating solar energy with electric vehicles, an area that continues to receive increasing attention in the research community. As solar technology matures, its potential to support and enhance the energy needs of EVs becomes increasingly significant.

In Chapter 2, "Introduction to EV Motors," the fundamental components of electric vehicle propulsion are examined. Understanding the operation and control of electric motors is critical to optimizing the performance of EVs. This chapter serves as an essential introduction to the various motor types, including their characteristics, advantages, and applications, providing readers with a solid foundation in EV motor technology.

Chapter 3, "Introduction to Power Electronics Converters," addresses the crucial role that power electronics play in the efficient operation of EV systems. These converters manage the flow of electrical energy between the battery, motor, and charging system. The chapter discusses the key converter technologies that facilitate the smooth and reliable operation of electric vehicles, and how these systems contribute to their overall performance and energy efficiency.

The discussion progresses with Chapter 4, "Field Oriented Speed Control of BLDC Motor for Practical Drive Cycle," which focuses on an advanced motor control strategy for electric vehicles. Field Oriented Control (FOC) of BLDC motors is a key method for enhancing performance and efficiency in real-world driving conditions. This chapter explains how this technique optimizes motor operation, allowing EVs to achieve higher levels of efficiency and performance during dynamic driving cycles.

In Chapter 5, "Phase Shifted Full Bridge Converter-based Battery Charger for Fast Charging of Electric Vehicles," the need for fast and efficient charging solutions is explored. This chapter introduces phase-shifted full bridge converters as a solution for rapid battery charging in EVs. By focusing on the optimization of charging times, this chapter addresses one of the most critical challenges faced by the EV industry—ensuring that electric vehicles are ready for use with minimal downtime.

Chapter 6, "An Adaptive Passivity-based Controller for Battery Charging Application: The Lagrangian Framework," presents an innovative approach to battery charging using a passivity-based controller. This chapter introduces the Lagrangian framework to optimize the charging process, ensuring that EV batteries are charged efficiently and safely, thereby extending their lifespan and improving overall vehicle performance.

In Chapter 7, "Vehicle-to-Grid (V2G) Battery Charging System for Electric Vehicles," we look at the bidirectional energy flow that allows electric vehicles to not only draw power from the grid but also return energy. The Vehicle-to-Grid (V2G) concept is a promising development in the integration of EVs with the broader energy grid. This chapter highlights the technical, economic, and regulatory aspects of V2G systems, and how they can support grid stability and energy sustainability.

Chapter 8, "IoT Based Floor Cleaning Electric Vehicle Robot with Live Streaming Camera," introduces the integration of Internet of Things (IoT) technologies with electric vehicles, specifically in the context of autonomous cleaning robots. This chapter highlights the application of advanced sensors, IoT connectivity, and robotics in the development of intelligent EV systems, extending the use of EV technologies beyond traditional transportation.

In Chapter 9, "Hardware Design and Modelling of Solar-Based Wireless Electric Vehicle Charging Station," the design and modeling of solar-powered wireless charging stations are explored. This chapter discusses the intersection of solar energy, wireless power transfer, and EV charging, providing insights into how these technologies can be integrated to create efficient, sustainable charging infrastructure for electric vehicles.

Finally, Chapter 10, "Hardware Design of Electric Bicycle with Solar Panel," closes the collection by addressing the design and development of solar-powered electric bicycles. This chapter emphasizes the growing trend of integrating renewable energy with lightweight personal transportation options, offering a glimpse into the future of urban mobility and clean, accessible transportation.

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# PREFACE

The rapid evolution of Electric Vehicles (EVs) and the increasing emphasis on sustainability have driven research in various fields, including solar energy integration, power electronics, and autonomous systems. This compilation of chapters offers a comprehensive review of the emerging technologies and methods that are shaping the future of Electric Vehicle (EV) systems. From advancements in solar energy harnessing to innovative control techniques for motor drives, this book explores the diverse landscape of research and development in EV technology, providing insights into both current trends and future opportunities.

Chapter 1, “A Review of Emerging Research Trends and Opportunities in Harnessing Solar Energy for Electric Vehicles,” sets the stage by discussing the growing role of solar energy in powering electric vehicles. This chapter outlines the potential benefits, challenges, and opportunities of integrating solar power with EV systems to create a more sustainable transportation solution.

In Chapter 2, “Introduction to EV Motors,” readers are introduced to the various types of motors used in electric vehicles, including their construction, operation, and performance characteristics. Understanding these motors is crucial to developing efficient EV systems that can meet the increasing demands for performance and energy efficiency.

Chapter 3, “Introduction to Power Electronics Converters,” explores the critical role that power electronics play in the operation of electric vehicles. This chapter provides an overview of the key converter technologies used in EVs, which are essential for controlling the power flow between the battery, motor, and other components.

The focus shifts to motor control in Chapter 4, “Field Oriented Speed Control of BLDC Motor for Practical Drive Cycle,” where advanced techniques for controlling Brushless Direct Current (BLDC) motors are discussed. This chapter emphasizes how these techniques contribute to the efficiency and performance of EVs during real-world driving cycles.

Chapter 5, “Phase Shifted Full Bridge Converter-based Battery Charger for Fast Charging of Electric Vehicles,” addresses the importance of fast and efficient charging solutions for EVs. The chapter delves into phase-shifted full bridge converters and their application in optimizing battery charging times without compromising system safety or longevity.

In Chapter 6, “An Adaptive Passivity-based Controller for Battery Charging Application: The Lagrangian Framework,” a novel controller is introduced that improves the adaptive charging of EV batteries. The chapter emphasizes the benefits of the Lagrangian framework in enhancing battery performance and overall energy management.

Chapter 7, “Vehicle-to-Grid (V2G) Battery Charging System for Electric Vehicles,” explores the potential of bidirectional charging systems, enabling EVs to not only charge from the grid but also contribute energy back to it. This chapter discusses the technological, economic, and regulatory challenges and opportunities of V2G systems in supporting grid stability and energy sustainability.

In Chapter 8, “IoT Based Floor Cleaning Electric Vehicle Robot with Live Streaming Camera,” the application of IoT and robotics in EV technology is highlighted. This chapter presents the design and operation of an autonomous floor-cleaning robot, showcasing how these innovations can be integrated into the broader field of electric vehicle development.

Chapter 9, "Hardware Design and Modelling of Solar-Based Wireless Electric Vehicle Charging Station," focuses on the integration of solar energy and wireless charging technologies. The chapter presents a hardware design for a solar-based charging station, demonstrating how these technologies can be combined to offer more sustainable and efficient EV charging solutions.

Lastly, Chapter 10, "Hardware Design of Electric Bicycle with Solar Panel," examines the design considerations and challenges in developing solar-powered electric bicycles. This chapter underscores the importance of solar energy in supporting the growing demand for sustainable urban mobility solutions.

Together, these chapters provide a holistic view of the current state and future directions of electric vehicle research, emphasizing innovative approaches to energy generation, storage, and management. As the world moves toward cleaner, more efficient transportation solutions, the research presented here offers valuable insights into the technologies that will shape the future of electric mobility.

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**CHAPTER 1**

# Comprehensive Review of Technological Advances in Solar EV Charging Systems and the Impact of Shading

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**Abstract:** This review provides a comprehensive overview of the technological advancements in solar Electric Vehicle (EV) charging systems, with a particular focus on the challenges posed by Partial Shading Conditions (PSC). As the adoption of electric vehicles grows globally, the integration of solar power for EV charging offers significant potential in reducing carbon emissions and optimizing energy efficiency. The review delves into the evolution of solar PV-EV charging systems, highlighting innovations in system designs, energy management strategies, and Vehicle-to-Grid (V2G) technologies. A key focus is placed on the impact of shading on Photovoltaic (PV) module performance, with an exploration of various mitigation strategies such as advanced optimization algorithms, hybrid PV systems, and battery storage solutions. Through a review of recent studies, it outlines the effectiveness of solar-powered charging infrastructure, including grid-connected and off-grid systems, in diverse environmental conditions. Despite the progress, challenges related to battery performance, system costs, and the feasibility of large-scale deployment are discussed. Furthermore, the review investigates the economic and environmental benefits of solar-assisted EV charging, with a focus on sustainability, cost reduction, and the integration of renewable energy sources. The chapter concludes by identifying future research directions to address the unresolved issues surrounding partial shading, battery degradation, and the optimization of solar charging systems for widespread adoption. Ultimately, it emphasizes the importance of overcoming shading effects to enhance the efficiency, reliability, and sustainability of solar EV charging systems, contributing to the broader goals of sustainable transportation and clean energy.

**Keywords:** Electrical vehicle, Partial shading, PV array, Solar power, Sustainable transportation.

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## INTRODUCTION

Electric Vehicles (EVs) running on solar power combine sustainable transportation with renewable energy. Even though modern EV solar panels cannot fully power the car, they can be used as additional sources of charging. By using sunlight to generate electricity, these panels extend the driving range and aid in battery charging. Nonetheless, there are still issues with panel integration and efficiency. The idea of an EV that runs entirely on solar power may become a reality as technology evolves. Engineers and researchers are working hard to optimize solar energy integration into electric vehicles. Innovative features encompass solar coatings that adapt to various surfaces and flexible solar panels that conform to the car's contours. Additionally, EVs can maximize solar charging based on sunlight availability and weather conditions thanks to smart charging systems. Even though completely solar-powered cars are still a way off, these developments bring us closer to a more sustainable and eco-friendly future.

The loss in power output from a partially shaded solar panel is not always proportional to the shaded area. In fact, partial shading can result in unbalanced energy losses. It is surprising to learn that a solar panel can drop to zero watts of output power from just a 10% shade. This occurs as a result of the dark cells having a substantial impact on the total current and power output. Fig. (**1**) shows the different conditions that cause partial shading, *i.e*., dust, snow, clouds, self-shading, trees, bird droppings, buildings, *etc*. The characteristic curve shows that when partial shading occurs, the maximum point is low with multiple peaks. The shading causes multiple peaks, *i.e*., global maxima along with local maxima in the current and power curve. The loss of power, *i.e*., mismatched power losses, and the loss of current, *i.e*., current loss, are shown in Fig. (**1**).

Solar panels in EVs currently serve as an auxiliary charging source, extending driving range and reducing reliance on grid power, though fully solar-powered EVs are not yet feasible. Technological advancements like flexible panels and smart charging systems are improving solar integration. Partial shading significantly reduces panel efficiency, causing mismatched power losses and multiple peaks in the current-power curve, which are influenced by the above factors. Section 2 discusses the technological advancement in SPV for EVs.

## TECHNOLOGICAL ADVANCES IN PV ARRAYS FOR EV CHARGING IN SHADED ENVIRONMENTS (2014-2024)

A case study to highlight the technical, economic, and regulatory challenges of the integration of solar energy systems into EV charging infrastructure has been presented [1]. Key technical issues include the design and optimization of solar PV systems, site suitability, panel efficiency, and grid integration. Regulatory barriers include interconnection standards, utility rules, and permitting processes. The study's analysis shows that solar-powered EV charging is feasible, with solar power generation and EV charging patterns well aligned. The findings provide valuable guidance for promoting sustainable energy and transportation electrification.

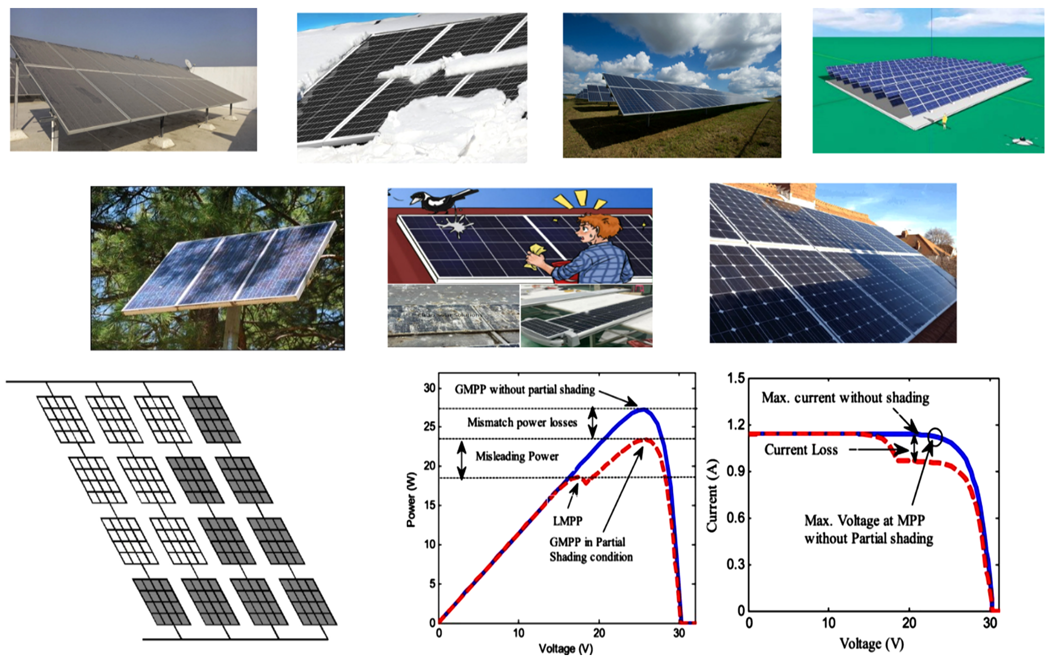


**Fig. (1).** Different conditions of partial shading.

A paper [2] explores using solar energy to charge EVs at workplaces for maximum energy yield and analyzes solar insolation variations to determine energy availability and the need for grid connection in the Netherlands. The study compares different EV charging profiles to minimize grid dependence and maximize solar power utilization, considering only weekday and daily charging scenarios. In addition to assessing the viability of incorporating local storage to cut grid dependence by 25%, a priority approach for managing several EVs charging from the same EV-PV charger is proposed. The study also investigates the design of a solar-powered EV charging station with a double-axis solar tracker, which enhances the energy yield by 17%, mainly in summer, and presents a storage size methodology adapted to different locations.

A new approach has been introduced to assess the effects of the full-battery effect and calculate the associated $CO_2$ reductions when conventional vehicles are charged with onboard solar power [3]. Using solar radiation and driver mobility

CHAPTER 2

# Introduction to EV Motors

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**Abstract:** This chapter provides a background of the study on Electric Vehicles (EVs), focusing on motor drive technologies that are still evolving. The need to optimize EV applications and performance is taken into account. EVs have been promising technologies for achieving a sustainable transport sector in the future due to their minimized carbon emissions, low noise, high efficiency, flexibility in grid operation, and integration. The future of EVs holds significant promise as advancements in technology and infrastructure converge. In general, Direct Current Motors (DCMs), Induction Motors (IMs), and Permanent Magnet Motors (PMMs) can generally be found in trading centers, whereas Reluctance Motors (RMs) have been utilized eventually and are approached towards commercial availability. This chapter briefly introduces various types of electric motors and their usage in electric vehicles. The reader will certainly have a basic understanding of motor mechanisms used in various applications of electric drives.

In the interest of the share market, let's analyze some figures to verify the usage and importance of electric vehicles in society. The annual EV sales crossed 12 lakh vehicles in FY2023, with more than 60% of the share accounted for by registered Electric two-Wheelers (E2W) followed by passenger Electric three-Wheelers (E3WP) with approximately 29% market share. The data also says that 13% of the new cars sold in 2022 were electric ones. The growth in $CO_2$ emissions should also be reduced in order to meet Net Zero Emissions by 2050. The share of sales of EVs increased by 4% in 2021. The global sales of battery electric vehicles (BEVs) and Plug-in Hybrid EVs (PHEVs) exceeded six million units in 2020.

**Keywords:** Battery pack, Charging infrastructure, Die-cast rotors, Electric car, Electric vehicles, Electric current, Electric motors, Electric traction systems, Greenhouse gas emissions, Induction motors, Internal combustion engine, Lorentz force, Net Zero Emissions, Permanent magnet motors, Power electronic converters, Reluctance motors, Rechargeable batteries, Switched reluctance machine, Two wheelers.

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## INTRODUCTION

EVs identify a transformative shift in the automotive industry, determined by a global journey of eco-friendly transportation. These vehicles rely on rechargeable batteries to store and supply electricity to electric motors, which drive the wheels. The aim is to reduce greenhouse gas emissions and mitigate environmental impact and dependence on fossil fuels. EVs include Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEVs), and many more, depending on the electrification level of the vehicle [1]. Fig. (**1**) shows the components of an electric car.

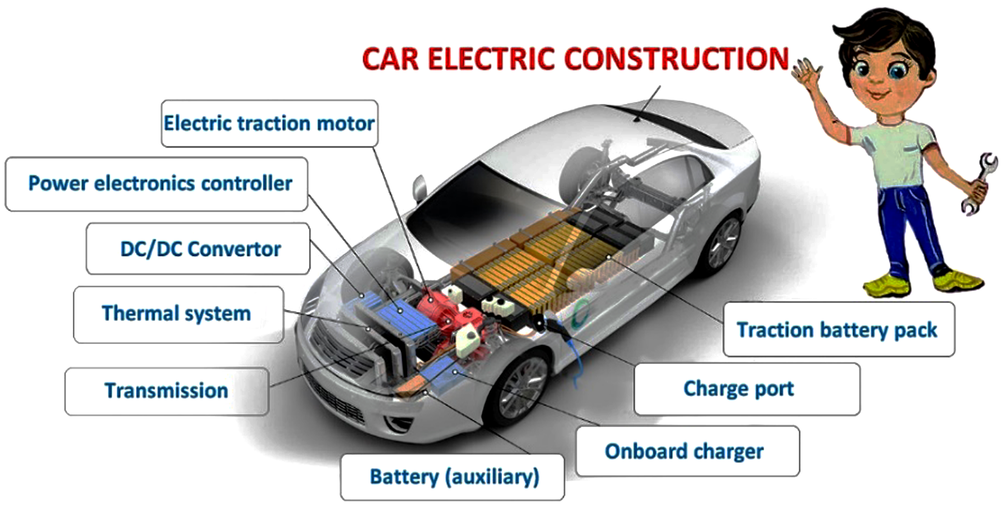


**Fig. (1).** Components of an electric car [3].

Components of electric vehicles include the battery pack, which serves as the energy storage unit, the electric motor, which serves as a contrast to combustion engines and delivers instant torque, resulting in responsive acceleration, and power electronic converters, which manage the flow of electrical energy between the battery and the electric motor. Ensuring optimal efficiency and charging plays a role in supporting worldwide adoption by addressing concerns related to range anxiety, convenience, and accessibility. Here is how charging infrastructure contributes to the widespread adoption of EVs. Advancement in fast charging technologies aims to reduce charging time and increase convenience for users. The oil crisis helped to conserve profit and funding for EV development. The insufficient energy density and increase in the cost of batteries made EVs less feasible in comparison with Internal Combustion (IC) engine automobiles. In urban areas, passenger vehicles have been the major source of air pollution. Therefore, we focus on this by introducing the pros of EVs. Electric traction systems are equipped with advanced capabilities such as increased fuel efficiency, quick charging options, and extended range [2].

The path to electrification is driven not only by environmental concerns but also by changing societal values. There is a growing consensus among governments, companies, and consumers regarding the necessity of shifting toward low-carbon technologies. Various measures, such as the European Union's Green Deal and China's New Energy Vehicle (NEV) program, have expedited the uptake of Electric Vehicles (EVs) through tax breaks, subsidies, and investments in infrastructure. In the U.S., the Inflation Reduction Act has played a crucial role in enhancing the EV market by fostering domestic battery manufacturing and developing extensive charging networks [3].

Electric Vehicles (EVs) also transform the driving experience by providing features like immediate acceleration, quiet operation, and reduced maintenance costs due to their less complex mechanical systems. These factors, along with their increasing affordability, make EVs attractive to a growing number of consumers. Additionally, as electricity grids evolve to include more renewable energy sources, the overall carbon footprint of EVs continues to decrease, further strengthening their sustainability appeal [4].

## CONCEPT OF EV MOTORS

Basically, the principle of Electric Vehicle (EV) motors revolves around electromagnetic induction, where electrical energy is converted into mechanical energy to drive the vehicle. Here is a breakdown of the fundamental principles involved in detail:

- Electromagnetic Induction: EV motors operate on the principle of electromagnetic induction, discovered by Michael Faraday in the 19th century. When an electric current flows through a conductor, it generates a magnetic field around the conductor. Conversely, when a magnetic field moves relative to a conductor, it induces an electric current in the conductor. This phenomenon is the basis of how electric motors work.
- Magnetic Fields and Coils: EV motors consist of coils of wire wound around a core, typically made of ferromagnetic material like iron. These coils, also known as windings, create magnetic fields when electric current flows through them. In a basic DC (Direct Current) motor, a permanent magnet provides the magnetic field, while in more advanced AC (Alternating Current) motors, the magnetic field is generated by electromagnets within the motor [5].
- Lorentz Force: When an electric current flows through the coils of an EV motor, it interacts with the magnetic field to produce a force known as the Lorentz force. This force causes the coils to experience a torque, resulting in rotational

CHAPTER 3

# Introduction to Power Electronics Converters

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**Abstract:** This chapter has been written keeping in mind that the electric vehicle is a multidisciplinary subject mainly involving electrical and mechanical engineering. So, the chapter begins by briefly discussing the basics of various semiconductor devices mainly used in the power electronic converters used for electric vehicles. This chapter clearly explains the requirement of power electronic converters to turn the electricity derived from an electric battery into a suitable form for an electric drive. It discusses the suitability of various semiconductor devices in different applications of drives based on switching and conduction losses. This chapter gives a comprehensive review of various power electronic converters used for electric drives. The former part of the chapter is dedicated to a detailed discussion of various configurations of DC-DC converters for electric drives with schematic diagrams, mathematical equations, and waveforms. In the later part of the chapter, a detailed discussion of various configurations of DC-AC converters for electric drives with schematic diagrams, mathematical equations, and waveforms is provided. This chapter also includes a comparison of various configurations to suit a particular kind of electric vehicle. For better understanding, the chapter also discusses speed control of induction motor drives using power electronic converters. A case study of the design and development of a bidirectional charger for electric vehicles is discussed on the MATLAB Simulink platform. Bidirectional chargers, which enable power flow in both directions from the grid to the vehicle (G2V) and from the vehicle to the grid (V2G), are at the forefront of this technological evolution.

**Keywords:** Bidirectional charger, Converters, Electric drive, Electric vehicle, Induction motor, Semiconductor devices.

## INTRODUCTION

The electrical energy readily available is of fixed frequency and fixed voltage type. For domestic and small commercial uses, mostly single-phase supply is available whereas industrial users draw supply from three-phase lines. Electric Vehicle charging and control requires a flexible power supply, wherein variable

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frequency and variable voltage may be available as per the various application-based requirements. To fulfil such industrial demands of conditioned power, power electronics converters are required. Power conditioning is an integrated term used for power conversion (from AC-DC and DC-AC) as well as power control [1].

Power converters are electrical networks consisting of a combination of semiconductor devices. Depending on the type of semiconductor device used, the converter can be uncontrolled, semi-controlled, or fully controlled. These semiconductor devices act as a controlled or uncontrolled switch in the power electronic converter. Power electronic converters can give the desired output by designing a proper switching strategy. In this way, with the use of these converters, the required input for industrial applications can be obtained [2].

In this chapter, a brief introduction to the most popular semiconductor devices has been given. The chapter gives a comprehensive review of power electronic converters used for electric drives. For a better understanding of the concept, a simulation of a converter for electric vehicle charging using MATLAB Simulink has also been included [3].

## Basics of Semiconductor Devices

In this section, we will give a brief overview of the most commonly used semiconductor devices to give an understanding of the selection of semiconductor switches for a particular application [1, 2]. There are a number of switches available in the market for different merits and demerits they offer, like Power Diodes, Bipolar Junction Transistor (BJT), Metal-oxide Semiconductor Field Effect Transistor (MOSFET), Insulated Gate Bipolar Transistor (IGBT), Silicon Controlled Rectifier (SCR), Gate turnoff switches (GTO), MOS controlled Thyristors (MCT), *etc* [4].

In this chapter, we will discuss the most popular semiconductor switches: 1) Silicon Controlled Rectifier (SCR), 2) Power-Metal-oxide Semiconductor Field Effect transistor (Power MOSFET), 3) Insulated Gate Bipolar Transistor (IGBT), *etc*. The focus of the chapter will be power electronic converters [5].

### *Silicon Controlled Rectifier (SCR)*

SCR is a 4-layer, 3-junction, 3-terminal pnpn semiconductor device, as shown in Fig. (**1**). The terminal connected to the exterior p layer is denoted as the anode (A), the terminal connected to the exterior n layer is denoted as the cathode (K), and the terminal connected to interior p layer is denoted as Gate (G). Fig. (**2**) shows VI characteristics of an SCR. The working of an SCR can be split into 3 modes of operation [6].

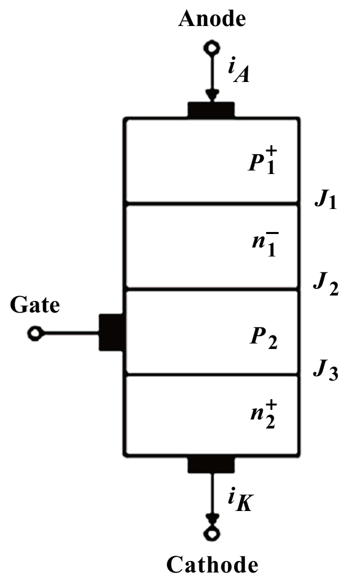


**Fig. (1).** Pnpn junction.

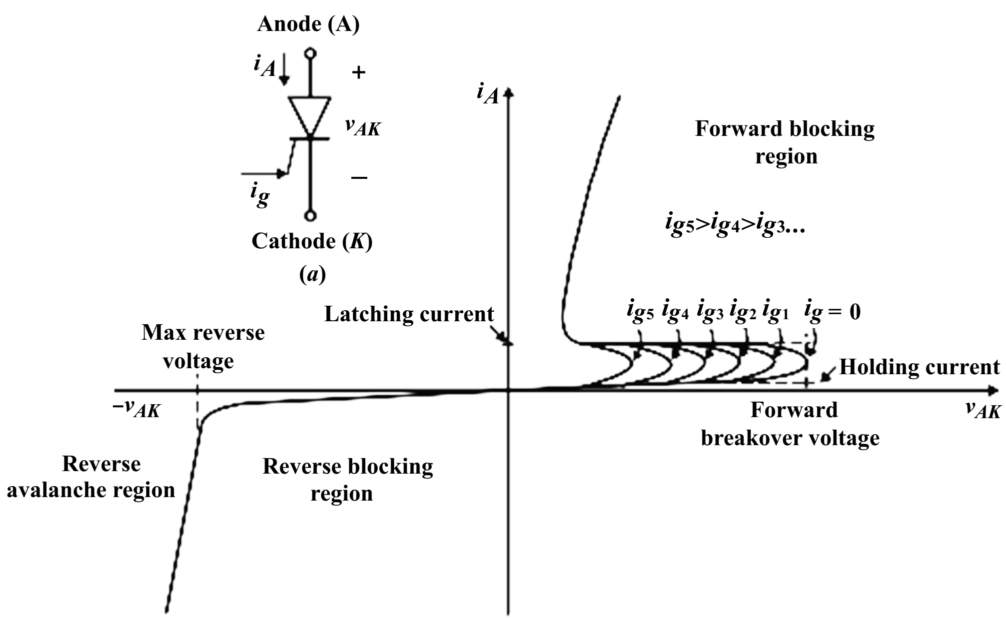


**Fig. (2).** (**a**) Symbol of an SCR (**b**)VI characteristics of an SCR.

## CHAPTER 4

# Field-Oriented Speed Control of BLDC Motor for Practical Drive Cycle

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**Abstract:** The widespread adoption of Electric Vehicles (EVs) relies on achieving high efficiency and precise motor control. Although Brushless DC (BLDC) motors offer advantages for EVs, traditional control methods struggle to deliver the desired performance. This chapter discusses the operation of BLDC and investigates the development and evaluation of a Field-Oriented Control (FOC) system that enables precise speed control of BLDC motors in an electric vehicle application. The developed FOC with necessary coding is provided for a clear understanding of the control. FOC offers superior control over more straightforward methods, allowing for independent torque and flux control, improving efficiency and dynamic response.

This research implemented a novel angle-based strategy within the FOC system. This approach controls the flux position of the motor using a constant 48V supply, significantly reducing switching losses compared to traditional PWM or PID control methods. Consequently, the system achieves a peak-to-peak speed ripple of less than 0.3 rpm and demonstrates improved efficiency. The machine dynamics, with the help of currents, fluxes, and changes in rotor position, are explained in this work.

A practical urban cycle is developed to test the proposed control topology. The successful operation of the vehicle with produced results highlights the effectiveness of the developed FOC system with the novel angle-based strategy in achieving precise speed control and improved efficiency for BLDC motors in EVs, contributing to the development of EVs with extended range and reduced environmental impact, paving the way for more sustainable transportation solutions.

**Keywords:** BLDC model, Back EMF, Developed torque, DC-AC inverter, Flux position estimation, Flux estimation, Hall effect sensing, Load variation, Position-based speed control, Practical drive cycle, Practical wheel RPM, Position sensor, Switching scheme of inverter, Speed tracking, Torque ripple.

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## INTRODUCTION

Electric Vehicles (EVs) have emerged as a better alternative for a cleaner and more sustainable transportation future with a proper energy management policy. However, the widespread adoption of EVs hinges on their ability to deliver a compelling driving experience and achieve exceptional levels of efficiency. At the heart of this challenge lies the electric motor, the workhorse responsible for propelling the vehicle. Brushless DC (BLDC) motors have garnered significant attention for their unique blend of desirable characteristics among various electric motor technologies. BLDC motors boast high efficiency, compact size, robust construction, and excellent torque-to-weight ratios – all crucial attributes for powering EVs effectively [1 - 13].

### Motors Used in EVs

The design currently, electric vehicles primarily rely on three main types of electric motors.

- AC Induction Motors: These motors offer a simple and robust design, making them a cost-effective choice for many EVs. The rotating magnetic field, produced by stator current in the stator windings, produces induced EMF to allow current in the rotor cage, generating torque. While AC induction motors are reliable and efficient, they typically offer less precise control than BLDC motors.
- Permanent Magnet Synchronous Motors (PMSMs): This category encompasses BLDC motors as a specific type. PMSMs utilize permanent magnet rotors and three-phase stationary windings on the stator. Like BLDC motors, PMSMs employ electronic control to regulate the current in the windings, creating a rotating magnetic field that interacts with the permanent magnets and generates torque. PMSMs, including BLDC motors, generally offer higher efficiency and superior controllability than AC induction motors. However, the presence of rare earth elements in the permanent magnets of some PMSMs can raise cost and sustainability concerns.
- DC Motors: These motors offer a simple design and high starting torque, making them suitable for low-speed electric vehicles such as neighborhood electric cars, golf carts, or industrial utility vehicles. However, DC motors generally have lower efficiency than AC induction motors and PMSMs, and brush wear can be a maintenance concern. Electric vehicle Charging facilities fall into two categories: slow and fast. Slow-charging systems, including Level-1 and Level-2 onboard charging configurations, are one of its types. Level-1 onboard systems typically charge one fully discharged battery for 8-10 hours. These systems are usually installed in residential areas and use power in the

range of 10 kW. On the other hand, Level-2 charging stations charge faster than Level-1 systems and are commonly found in public places, rated up to 20 kW.

Unlike brushed DC motors that utilize physical brushes for current commutation, BLDC motors employ permanent magnet rotors and stationary windings on the stator. The electronic controller orchestrates the switching sequence of these windings, generating a rotating magnetic field in the stator [14 - 16]. This rotating magnetic field interacts with the permanent magnets on the rotor, creating a force according to the Lorentz force principle. This force causes the rotor to spin, and by precisely controlling the sequence and timing of the current in the windings, the electronic controller dictates the speed and direction of the BLDC motor. This electronic control mechanism eliminates the friction and wear associated with brushes, leading to higher efficiency, longer lifespan, and smoother operation than traditional brushed DC motors.

Unleashing the full potential of BLDC motors in EVs necessitates implementing sophisticated control strategies. Traditional control methods, while functional, often need help to deliver the precise and efficient operation demanded by high-performance electric vehicles [17 - 25]. This is where Field-Oriented Control (FOC) steps in, revolutionizing the field of BLDC motor control.

BLDC Motors is considered very promising in modern drive technology. Their rapid gain in popularity increased different applications [26 - 30]. Some are automotive industry, consumer appliances, aerospace, industrial automation, and instrumentation.

Brushed DC Motors support the sub-kilowatt range drives and power generation for a long time. However, these applications were limited because of some control and material technology disadvantages. The recent development in integrating power electronics and digital control has allowed the small BLDC Motors to compete in price and performance.

A Brushless DC Motor is not similar to a Brushed DC Motor. The main difference is that the BLDC does not use brushes for commutation. Instead, the commutation is made unnecessary. In conventional Brushed DC Motors, the brushes make the rotor field almost fixed while the currents in the rotor windings change the direction. In contrast, the BLDC motor uses equivalent electronic commutation by shifting the relative position of the stator field concerning the rotor and thus eliminates the mechanically torn brushes.

**CHAPTER 5**

# Phase Shifted Full Bridge Converter-Based Battery Charger for Fast Charging of Electric Vehicles

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**Abstract:** The challenge of emission-free transportation is currently a much-discussed issue that has led to the development of innovative charging solutions. A major technical challenge for the potential market is the significant charging time involved, especially for long-range EVs. This chapter develops two design solutions: Phase-Shifted Full-Bridge (PSFB) Converter-based battery charger and grid-connected bidirectional charging schemes for a plug-in EV. A Constant-Current and Constant-Voltage (CC-CV) charging scheme is developed using industrial standards. The mathematical model of the EV Chargers has also been developed using the above control scheme to demonstrate Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) operations. The introductory part discusses the relevance of this topic, emphasizing the need for fast-charging technologies. After that, we discuss the available options for DC-DC converters and justify the choice of the PSFB converter, concluding with its design parameters. The following section compares two different control strategies for the DC-DC converter, leading to the choice of the CC-CV scheme and its implementation. Next comes the implementation of the 3-phase Controlled Rectifier, employing the d-q Current Control approach to regulate the rectifier through advanced direct-quadrature-coordinate controllers. The schemes are successfully implemented in the simulation environment for the considered operation mode. The results successfully present the charge controller performances with CC-CV charging for different batteries.

**Keywords:** Bi-directional converter, Battery SOC, Close loop current control, Control in d-q frame, CC-CV scheme, DC-DC converter, DC-AC Inverter, Grid connected operation, Grid to vehicle, Practical charging limit, Switching Scheme of Inverter, Voltage control, Vehicle to grid.

## INTRODUCTION

The world has to shift toward a sustainable future, pushed back by the inefficient use of fossil fuel-based energy. The adoption of Electric Vehicles (EVs) has

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surged in this context, with one primary challenge being the inconvenience and time-consuming nature of recharging compared to traditional refueling [1].

Under these circumstances, the fast charging of batteries offers the promise of significantly reducing the time required to recharge electric vehicles. This chapter deals with the intricacies of fast charging for electric vehicles, including its technological advancements, benefits, and challenges [2].

Electric vehicles are automobiles powered by rechargeable batteries or other energy storage systems storing electricity as fuel. Other than average Battery Electric Vehicles (BEVs) that run only on stored electrical power, another popular choice is Hybrid Electric Vehicles (HEVs), which use both an electric motor and a traditional IC engine [3].

Even with an excellent future for EVs, some barriers still need to be overcome, such as limited range between charges, long charging times, and inadequate infrastructure for charging points. However, with advances in battery technology and increasing concerns about environmental protection, the future looks bright for these vehicles, which can reduce the global carbon footprint [4].

### Charging Level of Electric Vehicles

The EV battery must float. Electric vehicle charging facilities fall into two categories: slow and fast. Slow-charging systems, including Level-1 and Level-2 onboard charging configurations, are one of its types. Level-1 onboard systems typically charge one fully discharged battery for 8-10 hours of charging time. These systems are usually installed in residential areas and use power in the range of 10 kW. On the other hand, Level-2 charging stations charge faster than Level-1 systems and are commonly found in public places, rated up to 20 kW [5].

As the EV market grows, faster charging options will also rise. The quick charging devices, categorized as Level-3, provide high currents capable of a complete battery replenishment in 30-40 minutes, normally operating up to 350 kW. Ultra-fast charging schemes of 400kW or above fully charge the battery in 20 minutes. The temperature limit of a battery is going to be the only constraint in this path of decreasing charging time. Table **1** presents the available types and levels of charging as reported by K. Zhou *et al.* [6].

## STATE-OF-THE-ART PRACTICES

The accelerated adoption of Electric Vehicles (EVs) has stimulated extensive research into fast charging technologies, which are pivotal for alleviating range anxiety and enhancing user convenience. This comprehensive literature review scrutinizes the evolutionary trajectory of fast-charging technologies for EVs, highlighting significant advancements, current obstacles, and prospects, explicitly focusing on DC-DC converters and battery controller design [7].

**Table 1. Electric vehicle charging types and levels.**

| Charging Type | Charging Location | Specifications | | | Charging Time | (Battery Capacity) | Criterion |
|---|---|---|---|---|---|---|---|
| | | Input/ Output Voltage (V) | Current (A) | Power (kW) | | | |
| **Level 1** | On-board | 120/230 | 12–16 | 1.44–1.92 | 11–36 h | 16–50 kWh | International Electrotechnical Commission (IEC) |
| **Level 2** | | 208/240 | 15–80 | 3.1–19.2 | 2–6 h | 16–30 kWh | |
| **Level 3 (Fast)** | Off-board | 300–600 | ≤400 | 50–350 | ≤30 min | 20–50 kWh | |
| **Ultra-fast** | | >800 | >400 | ≥400 | ≈10 min | 20–50 kWh | |

In the nascent stages of research, efforts primarily concentrated on augmenting charging efficiency and curtailing charging durations. Seminal works such as "Fast Charging Systems for Electric Vehicles" by Covic and Boys (2010) and "Development of a Fast Charger for Electric Vehicles" by Ueda *et al.* (2012) laid the foundational groundwork, emphasizing the critical role of DC-DC converters and battery controller design in enabling rapid charging [8].

Establishing uniform charging networks, epitomized by standards like CHAdeMO and Combined Charging System (CCS), facilitated market expansion by ensuring universal access to fast charging stations. Noteworthy studies such as Kato *et al.* (2014) on "Highly efficient, fast charging system for electric vehicles" and Liu *et al.* (2016) on "Development of high-power, fast charging station for electric vehicles" significantly contributed to the robust development of charging infrastructure, underscoring the importance of optimized DC-DC converters and advanced battery controllers.

Advancements in power electronics, particularly in DC-DC converters, have played a pivotal role in enhancing rapid charging capabilities. Research by Wang *et al.* (2018) on "Ultra-fast charging stations for electric vehicles: International development and China's experience" elucidated the significance of efficient DC-DC conversion in achieving ultra-fast charging speeds, while Zhang *et al.* explored factors influencing fast/rapid charging capacity for lithium-ion battery electric vehicles [9].

CHAPTER 6

# An Adaptive Passivity-based Controller for Battery Charging Application: The Lagrangian Framework

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**Abstract:** This chapter reveals the design and application of an adaptive passivity-based controller in the Lagrangian framework for the three-level (TL) boost converter as an EV battery charger. The proposed control technique is based upon the dynamic model of the proposed system along with the idea of energy shaping and damping injection. First, the state-space equations are developed using the EL formulation. Furthermore, the adaptive PBC on the average dynamics of the TL boost converters is designed along with the stability analysis. To reduce the steady-state errors and to obtain a robust controller against dynamics and external disturbances, a PI controller is added parallel to the proposed controller. The performances of the proposed controller are studied for two different loads (resistive and battery) under several operating conditions through MATLAB/ Simulink and tested through the OPAL-RT simulator. The power quality feature of the TL boost PFC converter is also assessed through total harmonic distortion of input source current under different operating conditions. Less than 5% total harmonic distortion is observed in the source current under various loading conditions, which lies in the range of international harmonic standard IEC 61000-3-2 Class C. Further, the comparative discussion of the proposed adaptive PBC with the PI controller is included in terms of peak overshoot, rise time, peak time and settling time.

**Keywords:** Adaptive passivity-based control, Euler-lagrange equation, Mathematical modeling, Three-level boost converter.

## INTRODUCTION

In recent years, Electric Vehicles (EVs) have been getting more attention due to their low transportation cost, low maintenance, high efficiency, and reduction in $CO_2$ emission as compared to internal combustion engines [1, 2]. For successful

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implementation of EVs, the battery chargers play a key role that must have a well-regulated DC power supply along with improved power qualities quality features like low THD and nearly unity power factor. The switched mode power converters are very popular for EV battery charging due to reduced losses, high efficiency, compact size, and lighter weight [3, 4]. The boost converter-based power factor correction is the most common for the design of general-purpose power supply because of its simple circuit that draws low-distorted input current from the supply main along with unity power factor [5, 6]. However, its switch experienced large switching stresses and switching losses that yielded low efficiency. Hence, a TL boost PFC converter topology is reported that reduces stresses on the switch as well as filter size by adding an additional capacitor, diode, and switch in the existing circuit [7, 8].

Several linear and non-linear controllers have been devised in the literature to achieve the desired output of the switched-mode power supply [9 - 15]. Conventionally, the switched power converters have been controlled with the help of fast controllers (P, PI, PID) [9]. Various non-linear control techniques have been reported [10-12] to improve the system's performance. In a study [10], an SMC approach is studied, which has robust features but suffers from chattering problems. In order to charge EV batteries, various control methodologies have been reported [11, 12]. The PI controller is employed for designing the EV battery charger [11]. It has the complex problem of tuning the controller parameters. In a study [12], the Fuzzy Logic Controller (FLC) is examined, and there is no need for either mathematical modelling or complex calculations, but there is no systematic and proper approach to designing the controller.

Recently, Passivity-Based Controllers (PBCs) have been extensively used to alter system energy by incorporating a virtual damping term that helps to achieve asymptotic stability, and the system becomes passive [13, 14]. The PBC in the Lagrangian framework for a conventional switched electrical system like a buck, boost, and buck-boost has been addressed [15, 16] and is explored in complex circuits [17]. Due to the non-minimum phase behaviour of the switched electrical system, an indirect control technique is employed, which controls the output voltage to the fixed value *via* input inductor current [13].

The PBC technique is also employed for the battery charging application using a bi-directional buck-boost converter [18]. The PBC in the Hamiltonian framework has been studied for several switched power converters in literature [19 - 21]. To improve the robustness of the controllers, an adaptive PBC methodology has been proposed [22 - 24]. In the adaptive passivity-based control technique, the system stabilises using adaptation laws with the help of the state estimators of uncertain parameters [23]. In a study [25], an adaptive sliding mode control scheme has been employed for a DC-DC converter with an unknown load.

Like non-linear controllers, passivity-based controllers also require accurate average dynamic equations of the system. Several efforts have been made for the mathematical modelling of nonlinear electrical networks using a power-based approach [26 - 28]. Initially, mathematical modelling of DC-DC power converters was presented by Middlebrook and Ćuk [26]. In a paper [27, 28], the classical Euler-Lagrange (EL) and Hamiltonian-based methodologies have been discussed.

The main contributions of this chapter include (i) the design of an adaptive PBC for the TL boost PFC converter, which facilitates regulated DC output voltage and improves power qualities like low THD and nearly unity power factor operation; (ii) Furthermore, stability analysis, eigenvalues and frequency response analysis are accomplished. (iii) The developed control law is validated through Simulink/MATLAB as well as through OPAL RT simulator. (iv) Additionally, the comparative discussion of the proposed adaptive PBC against the PI controller is included in terms of efficiency, THD, and various control parameters.

This chapter is structured in the following manner. In Section I, a brief introduction regarding the TL boost converter, EV battery charger, power factor correction, and PBC technique, along with the objective of the paper, are discussed. Section II explains the system configuration, modes of operation, and the dynamics of the TL boost converter. The adaptive PBC is introduced in section III. The stability analysis, eigenvalues, and frequency response of the system are also included in section III. Simulation results and comparative study, along with the test results, are discussed in section IV. Further, the conclusion is provided in section V.

## SYSTEM CONFIGURATION

A schematic diagram of the proposed system with the adaptive PBC is depicted in Fig. (**1**). The adaptive PBC is implemented in the anticipated system to provide controlled DC output voltage along with improved power quality. The adaptive controller includes adaption laws, which make the converter insensitive to parameter variations.

### Topology

The above circuit diagram (Fig. **1**) includes a single-phase diode bridge rectifier (DBR), a TL boost converter, a load (resistive or battery), and an adaptive PBC. The single-phase DBR is used to obtain a rectified sine wave $E$(t), from sinusoidal input source voltage, which acts as an input source for the TL boost converter.

**CHAPTER 7**

# Vehicle-to-Grid (V2G) Battery Charging System for Electric Vehicles

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**Abstract:** This study introduces a groundbreaking Vehicle-to-Grid (V2G) battery charging system tailored specifically for Electric Vehicles (EVs), accompanied by a comprehensive analysis and design methodology. The innovative technology facilitates bidirectional power flow, allowing energy to be transferred from the EV back to the grid or other interconnected devices, alongside conventional charging capabilities for EV batteries. This bidirectional functionality not only enhances the adaptability and efficiency of EV charging infrastructure but also holds significant promise for enhancing the resilience and stability of the grid. By enabling EVs to not only draw energy from the grid but also contribute surplus energy back when needed, the V2G system transforms EVs into flexible energy storage units. This capability can play a crucial role in mitigating grid imbalances caused by fluctuations in renewable energy generation or unexpected demand spikes. Moreover, during peak demand periods or emergencies, EVs can act as distributed energy resources, providing valuable support to the grid and reducing strain on traditional power generation facilities. The deployment of such a V2G system represents a paradigm shift in the way we approach both EV charging and grid management. It offers a sustainable solution to enhance grid resilience, reduce reliance on fossil fuels, and accommodate the growing demand for electric mobility. Additionally, the bidirectional power flow capability opens up opportunities for new revenue streams for EV owners through participation in energy markets or grid services.

**Keywords:** Battery, Electric grid, Optimization, Two-way communication, Vehicle fleet, Vehicle-to-Grid (V2G).

## INTRODUCTION

In response to the growing demand for sustainable transportation solutions, Electric Vehicles (EVs) have gained considerable attention in recent years. As the EV market continues to expand, there is a pressing need for innovative charging infrastructure capable of accommodating the diverse requirements of EV owners

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and grid operators. Electric vehicles (EVs) emit less carbon dioxide, and the price of fossil fuels is rising; they are now more competitively priced than conventional internal combustion engine vehicles [1]. However, a number of drawbacks, including high car costs, lack of adequate charging infrastructure, and short all-electric drive range, prevent EVs from being widely used in the market [2]. Furthermore, there are many difficult problems when EVs are integrated into the power system. For example, a high degree of EV charging penetration results in higher power grid loading. The revolutionary concept of Vehicle-to-Grid (V2G) involves the use of Electric Vehicle (EV) batteries for energy storage. V2G enables regulated power injection into the grid based on predetermined schedules and pricing structures, allowing EV owners and power utilities to interact dynamically in contrast to normal EV charging. There are several advantages to this mutually beneficial interaction between EVs and grids. When considering V2G from the perspective of power utilities, several benefits are introduced, such as load levelling, harmonic attenuation, reactive power supply, active power regulation, and mitigation of peak loads. Simultaneously, by charging for grid involvement, EV owners can monetize the energy stored in their cars [3 - 5]. The majority of EV chargers that are sold commercially are now made to operate in only one way, which limits their use for slow or fast charging. However, for V2G to be implemented, specific EV chargers that can transfer power in both directions between the EV batteries and the grid are needed. This study proposes a revolutionary bidirectional EV battery charger with a creative control scheme in response to this need. The four operational modes that can be achieved using the proposed control technique are fast charging, rapid discharging, slow charging, and gradual discharging. This adaptability allows for a variety of charging circumstances to ensure effective grid integration and optimal energy management [6, 7].

The Vehicle-to-Grid (V2G) Battery Charging System is a disruptive technology that enables bidirectional energy flow between electric vehicles and the power grid. Unlike traditional charging systems that only draw power from the grid, V2G systems allow EVs to send excess stored energy back to the grid. This capability supports energy efficiency, grid stability, and the integration of renewable energy sources, making it a cornerstone for the future of sustainable energy systems.

The primary functionality of V2G systems is to act as energy consumers and suppliers. When grid demand is low, EVs can charge their batteries, usually benefiting from lower electricity prices. Conversely, in peak demand or emergencies, they can discharge stored energy back into the grid when used as mobile energy storage. This bidirectional energy flow helps stabilize the grid, reduces reliance on fossil-fuel-based power plants during high demand, and improves the overall efficiency of energy systems.

A V2G system usually consists of advanced hardware, such as bi-directional chargers, and software that handles the energy flow. Communication protocols, like ISO 15118, will allow for smooth interaction between the EV, the charging infrastructure, and the grid. Smart charging capabilities will allow these systems to optimize energy usage based on the needs of the grid, the cost of electricity, and the needs of the user for their travel, so the vehicle is always ready when it is needed.

One of the main benefits of V2G technology is the opportunity to deliver economic advantages to EV owners. In that manner, selling unused energy back to the grid allows the owner to offset costs from charging. Moreover, the role of V2G systems is important for boosting grid reliability. When an outage or disruption occurs, it is capable of providing backup power to residences and commercial establishments.

Despite the many benefits of V2G technology, there are a number of challenges. The investment needed for V2G-compatible infrastructure is quite high, and charge-discharge cycles are known to accelerate battery degradation. Regulatory frameworks and market structures to support V2G are still developing, and consumer awareness about the technology is limited. These will be critical in ensuring that V2G systems become widely adopted.

Looking ahead, V2G technology is going to shift the very thinking about energy systems and change everything in a very short period of time. Growing investments in smart grids, renewable energy, and battery technologies give V2G better sustainability and efficiency in making energy systems. As barriers continue to be overcome together by governments, automakers, and energy providers, integration of V2G systems could likely be an integral part of the global energy transition.

## AGGREGATOR TECHNOLOGY GRID-BASED VEHICLE

### Aggregator Strategy

Scholars in academia and industry are investigating various Vehicle-to-Grid (V2G) aggregation strategies [8]. The particular goals of the control system usually determine the aggregation approach that is chosen. The goal of optimal aggregation solutions is to minimize cost functions related to energy bills for preset grid utilities, or in other words, to lower the charging costs for owners of electric vehicles (EVs). Various ancillary service markets, such as regulation,

**CHAPTER 8**

# IoT Based Floor Cleaning Electric Vehicle Robot with Live Streaming Camera

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**Abstract:** The integration of Internet of Things (IoT) technology in domestic automation has revolutionized household applications, including floor cleaning. Automated Floor cleaning is a very useful application in the field of Electrical Vehicle technology that is helpful in household as well as industrial applications. This paper presents a brief overview of the basic structure and components of a floor-cleaning vehicle. Also, this paper presents a detailed literature review on various topologies involved in robots for floor cleaning systems. The ultimate objective is to engineer an independent cleaning solution that not only excels at thorough and efficient floor cleaning but also provides users with the ability to monitor the process in real-time. The proposed system harnesses a sophisticated array of sensors, microcontrollers, and a Wi-Fi module, establishing a seamless channel of communication between the cleaning robot and a remote user interface. The cleaning mechanism is designed to incorporate precision brushes and powerful vacuum functionality, ensuring the effective removal of dust and debris from a wide range of floor surfaces. Moreover, the integration of a live streaming camera on the robot presents users with the unique opportunity to closely observe the cleaning process as it unfolds, accessible *via* a user-friendly mobile application or web interface. Key features of the system include efficient path planning, obstacle detection and avoidance, and remote monitoring *via* live streaming. This research contributes to the field of smart home technology by offering a practical and innovative solution for automated floor cleaning. In the future, machine learning algorithms will be developed in the proposed system.

**Keywords:** Automated floor cleaning robot, Electric vehicle, Microcontroller, Robot.

## INTRODUCTION

The rapid advancement of electrical vehicle-based robotic cleaners has gained significant attention in the field of robotics. These innovative devices have proven

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to be highly effective in aiding humans with floor-cleaning tasks in various settings such as homes, hotels, restaurants, offices, hospitals, workshops, warehouses, and universities. Robotic cleaners excel in diverse cleaning abilities, including floor mopping and dry vacuuming. While some models utilize simple obstacle avoidance with infrared sensors, others employ more advanced laser mapping techniques. The cleaning and operating mechanisms of robotic floor cleaners each have unique benefits and drawbacks. For instance, robots using laser mapping are faster, more efficient, and save energy, but can be costly. On the other hand, obstacle avoidance-based robots are more affordable but may be less energy-efficient and time-consuming due to random cleaning patterns.

The main objective of this work is to discuss the basic structure of a typical floor-cleaning robot and provide a literature review on various types of floor-cleaning robots for the household as well as industrial applications. Along with that, this paper proposes a floor-cleaning robot that provides a considerable solution to the problem of manufacturing robotic cleaners utilizing local resources while keeping low costs. In this work, a "live streaming smart floor cleaning robot" has been intended for customer or organization purposes. The proposed design has the facility of livestreaming, by which, a user can monitor the process from a remote place.

This paper is organized into five sections. The first section is committed to the introduction of the floor-cleaning robot. The second section is dedicated to the basic structure of a floor-cleaning robot. In the third section, a brief review of floor-cleaning robots is discussed. In the fourth section, a brief on the proposed live-streaming robot has been discussed. The fifth and the last section is dedicated to the conclusions of the work.

## METHODOLOGY

Fig. (**1**) presents the decisive steps taken in the development of the robot prototype. The autonomous floor cleaning system features an array of sensors strategically positioned around and beneath the robot chassis. Notably, these sensors consist of one ultrasonic sensor and three infrared sensors, providing robust guidance to the robot for effective collision avoidance.

To ensure efficient cleaning, wipers are powered by a motor, while a water pump delivers water to the mop at regular intervals for mopping. The entire robotic system operates on a rechargeable battery and can be controlled *via* Android-based or other applications, allowing for remote operation within a range of about 10 m. Once the cleaning is complete, the dirt container is emptied, and the mop cloth is replaced. Fig. (**2**) illustrates the various components used in the prototype, with detailed descriptions provided in the following sections.

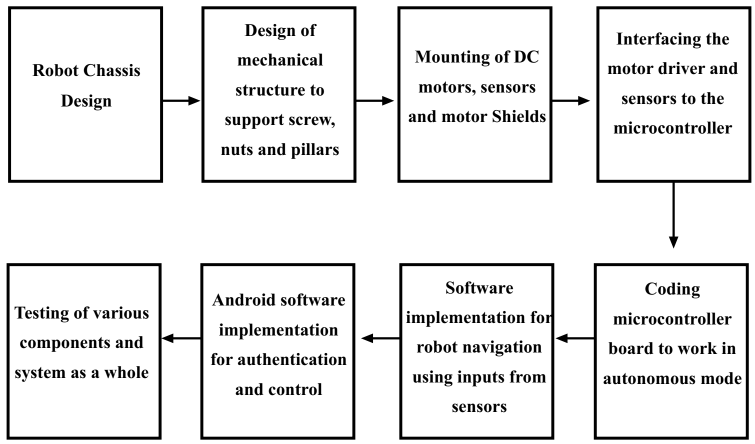


**Fig. (1).** Steps involved in the implementation of electrical vehicle-based robotic cleaners.


**Fig. (2).** Components Involved in Electrical Vehicle-Based Robotic Cleaners.

## Microcontroller

Node MCU boards have become indispensable for the implementation of cutting-edge robotics and IoT projects. They integrate a microcontroller and an Integrated Development Environment (IDE) for seamless programming. The Node MCU, as a low-cost, open-source IoT platform, harmoniously combines the ESP8266 Wi-Fi SoC from Expressive Systems with the Node MCU firmware, making it a versatile and powerful choice for our work.

CHAPTER 9

# Hardware Design and Modelling of Solar based Wireless Electric Vehicle Charging Station

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**Abstract:** This chapter proposes a model for a wireless charging station for Electric Vehicles (EVs), eliminating the need for conventional charging plugs and wires. The system operates based on the principle of mutual induction, utilizing two coils: a transmitter (primary coil) and a receiver (secondary coil). In this setup, the primary coil is powered by a high-frequency AC supply source/inverter, and EMF is automatically in the IC field. When the secondary coil, located in the vehicle, comes into proximity with the primary coil, an Electromagnetic Force (EMF) is induced in the receiver coil, allowing energy transfer without physical contact. A key feature of this model is that the two coils are not co-located. The primary coil is installed at the charging station, while the secondary coil is integrated into the electric vehicle. For the system to work, the vehicle must be equipped with this secondary coil. Once energy is transferred from the primary to the secondary coil, it is used to charge the vehicle's batteries. In addition to facilitating wireless charging, the station is powered primarily by solar energy, making it an eco-friendly solution by utilizing renewable energy sources. Importantly, electric vehicles without the secondary coil installed will not be compatible with this wireless charging system, underscoring the need for integration of this technology into the vehicle design.

**Keywords:** Compensation, Green renewable source, Inductive power transfer, Resonant power transfer, WPT.

## INTRODUCTION

Electric vehicles around the world are being charged by wired charging methods at various electric charging stations. All these stations have overhead electricity or diesel generators as their input source of energy. Diesel engines were already a responsible source of pollution, and the grid's inputs just supported the pollution level because about 50 percent of electrical energy is still generated by conven-

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tional non-renewable resources. Most people think that just using electric vehicles and charging stations reduces the pollution in the environment, but it is not 100% true. This is because if you are taking energy from charging stations from the grid supply, then there is no difference in the level of pollution as electricity is eventually generated by coal and some other conventional sources [1]. You are just converting dispersed pollution into concentrated one without any reduction in level. If we go deep, we see that the overall pollution increases despite being reduced. It is because there are losses at various stages of transmission and distribution, and the generating station has to feed those losses, too. So, coal consumption increases for the same energy at the vehicle level, and thus, pollution and carbon emissions slightly increase. The only way to truly reduce pollution is by using non-conventional or renewable sources. These sources have no meaning to coal or the grid, and they can be autonomous sources with net zero emission of carbon and their subsidiaries [2].

This charging station uses the energy of a green renewable source, *i.e.*, solar energy, as the input and converts it into AC electricity after some controller circuitry and devices. This minimizes the energy intake and dependency on electric vehicles to charge electricity to utility companies alone [3]. Electricity is transferred from the station to the vehicle through inductive and resonant wireless charging in AC form, which is further rectified and regulated by the vehicle's internal circuitry. It also employs the overhead AC utility provided by the government in case solar rays are unavailable. This increases the reliability of the station [4].

An electric vehicle is a means of transport that needs electricity as the input fuel to the system. Since electric vehicles, instead of using an inter-combustion engine, employ electric motors for the propulsion, and this motor can be DC/AC, which is fed by the series and parallel combination of batteries through various power electronic converters, they depend most severely on charging infrastructure [5]. Batteries used in vehicles are lead storage in most EVs, but some hi-tech EVs can use a huge combination of lithium-ion batteries. The advantage of lithium-ion batteries is their high energy density. It also has the challenge of proper charging and discharging maintenance, as these batteries are more prone to explosions. That's why proper BMS is employed in those systems that employ Li-ion batteries to store electricity [6].

The charging station has both steady and quick charging features, such as level 1 and level 2 charging, respectively. Fast or level 2 charging can be done for vehicles in an emergency. However, steady charging is far better than quick charging from the battery's life point of view. This is because if we charge the battery rapidly, it takes up a lot of current and produces heat inside the battery.

Chemical reactions are fast and quick, which leads to a decrease in the storage capacity of the batteries [7]. The life of batteries is often recognized by a number of cycles, *i.e.* no. of charge and discharge in a battery's life, and it is much affected by the way a battery is charged and used. For the best performance and results with longevity, steady charging with a proper battery management system is required. Talking about lithium batteries (whether it be lithium ion or lithium polymer), they have high risks of explosions. This is because lithium is the most reactive metal element in the periodic table. However, it has a very high energy density and efficiency with lesser weight per unit of energy and power compared to other storage devices (batteries). This is the reason why most EV manufacturers use and promote lithium batteries. The lithium sector has undergone a new revolution after the discovery of lithium sources in the United States of America and China [8].

In the charging infrastructure, an inverter section connects DC and AC links. This is basically a high-frequency inverter with a ferrite core transformer. It is somewhat different from conventional domestic inverter. It is because it does not produce output at power frequency. It has its output at super higher frequencies at some kilohertz or megahertz. Using higher frequency is the demand of the charging station in order to make wireless power transfer efficient. At higher frequencies, the required flux for the mutual induction decreases, and thus, the loss of flux is also minimized [9]. In order to make this system further efficient, a technology called resonant wireless power transfer is used. It makes coupling between the primary transmitter and secondary receiver coils *via* resonance. Both coils resonate at the same frequency, and it gives maximum efficiency. Moreover, it supports multiple secondaries at the same time. There is a compensation network that includes capacitors and inductors in both the transmitter and receiver in order to match the impedances exactly [10]. Various measuring instruments are used to measure the output voltage, current, power, and energy. Measuring energy is the most crucial thing when building a project like a charging station because consumers have to pay bills for the electrical energy they use to charge their vehicles [11].

The charging pad design is important as it transfers the power to the vehicle's receiver coil. For the transmitter and receiver coil, a litz wire with a proper diameter and cross-sectional area according to the requirement is used. This wire is hollow from the inside, and it is important in this application. Whenever we use alternating current, we observe that current density is higher, mostly near the surface of the wire, and almost zero at the center. In other words, we can say that most of the current flow through the surface, and this alternating current effect is called the skin effect. This is mainly due to the inductance and inductive reactance, which are directly proportional to supply frequency. So, to better utilize

## CHAPTER 10

# Hardware Design of Electric Bicycle with Solar Panel

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**Abstract:** Solar energy manifests as rays and heat emitted by the sun. Solar panels consist of solar cells that convert light into electrical energy. The contemporary landscape calls for innovative solutions to combat fuel dependency and environmental degradation, with a solar hybrid bicycle system emerging as a promising remedy. The escalating emission of carbon dioxide from vehicular exhausts exacerbates the pace of global warming. Concurrently, the relentless surge in fuel prices across India and globally underscores the imperative to explore alternative avenues and harness natural resources judiciously. The integration of a hybrid solar bicycle system presents a tangible opportunity to mitigate $CO^2$ emissions and curtail fuel expenses. The solar bicycle epitomizes an electric vehicle paradigm, leveraging solar energy to replenish its battery reserves and power its motor. Endowed with nine months of abundant sunshine annually, India stands poised to reap substantial benefits from such innovative transportation solutions. The hybrid bicycle, crafted to amalgamate solar energy and a dynamo-driven battery charging mechanism, embodies a sustainable mode of transportation. Integral to the operational framework is an accelerator mechanism facilitating motor speed regulation, thereby ensuring optimal control over power supply. This fusion of renewable energy and conventional cycling components heralds a paradigm shift in sustainable mobility solutions. By harnessing solar power and kinetic energy through the dynamo, the hybrid bicycle exemplifies an environmentally conscious mode of transport conducive to reducing carbon emissions and alleviating fuel dependency. The advent of the solar hybrid bicycle system symbolizes a pivotal stride towards addressing contemporary challenges associated with fuel consumption and environmental degradation. With India's climatic predisposition favoring solar energy utilization, the proliferation of such innovative transportation solutions holds promise for ushering in a greener, more sustainable future.

**Keywords:** Controller, Electric vehicle, Electric two wheelers, Hardware architecture, Hub BLDC motor, Solar based vehicle.

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## INTRODUCTION

Solar panels, comprising solar cells that convert light into electrical energy, have served as the focal point of research exploring their application in charging electric bicycle batteries [1]. The study unveils an electric bicycle powered by a 24V, 12Ah battery, requiring 9 hours and 33 minutes to charge with a 250W DC motor. As anticipated, the solar-panel-equipped electric bicycle attains a maximum speed of 17 km/h, covering a distance of 15 km with an 80 kg load [2]. The significant energy output from sunlight solidified solar panels as a reliable alternative energy solution for tomorrow's needs, offering sustainability and potential independence from traditional power sources [3]. Introducing solar panel electric bicycles marks a paradigm shift by enabling battery charging while in motion. In instances of insufficient sunlight, battery charging can be supplemented by electrical power through a battery charger connected *via* the controller [4]. This feature not only saves money in Indian currency by reducing reliance on precious fossil fuels but also ensures operational quietness and versatility in emergency or cloudy weather conditions [5]. Hence, a solar bicycle emerges as an electric motor vehicle powered by solar energy, providing the requisite voltages to operate the motor. Numerous cities have initiated vehicle development programs centered around bicycles, with electric bicycles serving as a prominent category [6]. These electric vehicles, including solar-powered bicycles, often incorporate charging systems powered by photovoltaic panels [7]. A solar bicycle can be connected to a charging station, facilitating battery charging in a stationary state. The inception of this project stemmed from existing socio-economic factors, aiming to provide affordable and efficient transportation, especially in rural India, characterized by rugged terrain predominantly comprising steep hills. The solar-powered bicycle epitomizes the transition towards sustainable energy sources [8]. While bicycles are inherently sustainable, this project enhances efficiency and fosters awareness among the masses. The solar hybrid bicycle reduces fossil fuel usage and mitigates pollution [9]. By harnessing solar energy for propulsion, the bicycle addresses both environmental concerns and energy supply challenges in remote areas. Urban mobility issues, exacerbated by traffic congestion, fuel consumption, and air pollution, necessitate sustainable transportation solutions. Electric bicycles, particularly those powered by solar energy, offer a clean, cost-effective alternative [10]. Cycling's numerous advantages have offered an effective answer to urban mobility issues, especially for short journeys, providing sustainability and health benefits. Solar bicycles leverage India's predominantly sunny climate, exploiting renewable energy advantages and replacing conventional bikes as the mode of transport [11]. Bicycles operate by converting solar energy into electrical energy, stored in batteries to fuel the hub motor, facilitating movement without relying solely on physical exertion [12]. Solar panels mounted on the carriage will charge the battery, ensuring continuous operation even during the night [13]. The solar bicycle's working mechanism involves four stages. Solar panels initially converted sunlight into electrical energy through the photovoltaic effect, harnessing sunlight's power for electricity generation. Subsequently, a motor controller and DC boost converter regulate and amplify voltage [14]. The energy is then stored in batteries and supplied to the brushless DC motor, mounted on the rear wheel, providing efficient and quiet propulsion. Finally, the sprocket and chain drive mechanism propels the bicycle forward [15]. This research underscores the transformative potential of solar-powered electric bicycles in addressing both environmental and socio-economic challenges [16]. Through the use of renewable energy sources, such innovations are paving the way for a greener, more sustainable future in transportation [17].

## METHODOLOGY

The methodology behind the electric bicycle, particularly one powered by solar energy, encompasses a multifaceted approach integrating various components and technologies to enable efficient and sustainable transportation [12]. The electric bicycle functions by harnessing renewable energy and converting it into mechanical propulsion, thus decreasing dependency on fossil fuels and lessening environmental harm. The foundation of the electric bicycle lies in its power source, which typically comprises a combination of solar panels and rechargeable batteries. Solar panels, consisting of interconnected solar cells, are strategically mounted on the bicycle to capture sunlight and convert it into electrical energy through the photovoltaic effect. These panels are often positioned on the carriage or integrated into the bicycle frame, maximizing exposure to sunlight while maintaining aerodynamic efficiency. Once solar energy is harvested, it undergoes a series of conversions and transformations within the bicycle's electrical system [15]. The solar panel-generated electrical energy is directed to a charge controller, regulating voltage and current for safe, efficient battery charging, ensuring optimal performance and prolonging battery life. This controller serves as a crucial interface between the solar panels and the battery, optimizing energy transfer and storage [18]. Simultaneously, the electrical energy is directed towards charging the onboard batteries, typically lithium-ion or lead-acid batteries, depending on the specific design and requirements of the electric bicycle. These batteries act as energy reservoirs, storing excess solar energy during periods of sunlight for later use when solar irradiance is insufficient or during nighttime operation. The charging process is managed intelligently by the battery management system, which monitors battery health, prevents overcharging, and optimizes energy utilization [19]. The heart of the electric bicycle lies in its propulsion system, comprising a motor and drivetrain mechanism responsible for converting electrical energy into mechanical motion. Electric bicycles commonly

# Conclusion and Future Scope

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**Chapter 1**, "A Review of Emerging Research Trends and Opportunities in Harnessing Solar Energy for Electric Vehicles", discussed how Electric vehicle (EV) and solar energy integration have advanced significantly, tackling the dual problems of sustainable energy production and transportation. Knowledge of photovoltaic (PV) technology, energy conversion efficiency, and storage systems has advanced significantly in academia. Research has concentrated on optimising the integration of solar energy into EV powertrains and charging systems, as well as increasing the power output of solar panels through technologies like perovskite and multi-junction cells. Notwithstanding these advancements, issues like solar energy's erratic nature and the shortcomings of current energy storage systems are still being researched.

The commercialisation of solar-powered electric vehicle technology is accelerating from an industrial standpoint. Businesses are investigating hybrid solutions that blend conventional grid-based charging with renewable energy sources and solar-integrated charging stations. Products like mobile solar charging stations and car solar roofs have started reaching niche markets. However, more advancements and financial investments are needed to scale these technologies to satisfy mass-market demands and guarantee economic viability.

Socially, popular and governmental support for solar-assisted EV solutions is being driven by the growing awareness of environmental sustainability and the advantages of renewable energy. Adoption rates are rising as a result of financial incentives and policies supporting renewable energy. However, obstacles like the absence of extensive infrastructure for charging and the expensive upfront costs of solar-integrated systems still prevent universal access, especially in developing nations.

## Future Directions in Harnessing Solar Energy for Electric Vehicles: Insights from Emerging Research Trends

Research in the upcoming years will probably concentrate on removing the technological obstacles that presently prevent the integration of solar and electric vehicles. It will continue to be a top goal to increase PV cell efficiency using cutting-edge materials like perovskite and quantum dot-based cells. Solar energy is now more feasible for automotive applications because of these technologies, which offer increased energy yields and reduced prices. Furthermore, it is anticipated that the creation of predictive energy management systems that use artificial intelligence (AI) and machine learning would dynamically optimise energy use to overcome the unpredictability of solar power. Additionally, hybrid energy solutions that integrate solar energy with other renewable resources like wind or hydrogen are expected to become more popular to enhance energy availability and dependability.

In the industrial sector, the emphasis will shift to increasing production capacity in order to more economically produce solar-integrated EV components. The secret to guaranteeing smooth integration without sacrificing performance or design will be lightweight, flexible, and long-lasting solar panels made especially for automobiles. Advancements in modular solar charging stations that can operate in both off-grid and urban settings will serve a wider range of users. In autonomous EVs, where self-sufficient energy systems are necessary for prolonged operations, industries will also investigate the use of solar energy.

The shift to solar-powered EVs will necessitate strong legislative frameworks and extensive public education from a sociological perspective. It is anticipated that governments will play a significant role in promoting the use of solar-assisted EVs through the implementation of regulations, tax breaks, and subsidies. To increase the knowledge of these technologies' long-term cost savings and environmental advantages, educational programs will be required. Ensuring that these solutions are accessible in underserved and rural areas will be crucial in facilitating their equitable adoption across socio-economic divides. The urban-rural divide will be lessened with the support of community-driven renewable energy projects and partnerships between public and private organisations.

A revolutionary change to create sustainable energy and transportation systems is presented by the combination of solar energy with electric vehicle technologies. The industrial sector is responsible for converting these developments into scalable, market-ready solutions, while the academic community continues to tackle basic issues pertaining to efficiency, storage, and control. Socially, fair access, encouraging legislation, and public involvement are all necessary for solar-EV systems to succeed. A cleaner, more sustainable, and renewable-powered transportation ecosystem will become a reality when these factors come together, ensuring a more efficient and environmentally friendly future.

**Chapter 2**, "Introduction to EV Motors", explores how the demand for environmentally friendly transportation options has propelled substantial advancements in the field of Electric Vehicle (EV) motors. Many motor technologies, such as brushed DC motors, brushless DC (BLDC) motors, induction motors, and Permanent Magnet Synchronous Motors (PMSMs), have been the subject of in-depth scholarly investigation. Efficiency, torque performance, and compatibility for particular EV applications are just a few of the distinct benefits that each type of motor offers. In order to precisely regulate speed and torque, significant advancements have also been achieved in our understanding of motor control systems, including Direct Torque Control (DTC) and Field-Oriented Control (FOC). Nevertheless, reducing heat losses, increasing energy efficiency, and addressing material dependencies such as using rare earth metals in magnets remain difficult tasks.

With an emphasis on mass production and modular designs, EV motors have improved in efficiency, dependability, and affordability from an industrial standpoint. Compact designs, improved thermal management, and higher power densities have all been made possible by manufacturing techniques and materials developments. By creating alternative motor designs like Switching Reluctance Motors (SRMs), industry leaders are attempting to lessen reliance on rare earth elements. However, there are still issues with these inventions' scalability and incorporation into cost-sensitive sectors.

Socially speaking, the increasing popularity of EVs has raised awareness of motor technology as an essential part of sustainable mobility. Demand has been fuelled by government policies and subsidies, as well as public knowledge of the environmental advantages of EVs. However, researchers and producers are under tremendous pressure to develop quickly while maintaining affordable costs for the general public because of social expectations for affordability, range, and performance.

## Future Directions in Electric Vehicle Motor Development: Insights from Emerging Trends and Technologies

Academic research in the upcoming years will probably concentrate on improving EV motor performance and efficiency even more. Research on new materials, like high-temperature superconductors and sophisticated composites, may result in innovations that improve thermal performance and lower energy losses. In order to reduce system weight and improve compactness, a major area of study will also be the development of integrated motor-inverter systems. Enhanced modelling and simulation methods powered by AI and machine learning will be anticipated to optimise motor design and control schemes for particular driving circumstances, improving performance in various applications.

Concerns about cost and sustainability will be addressed as manufacturers work to improve motor designs for mass-market adoption. With developments in switching reluctance and ferrite-based motors, efforts to lessen or completely eradicate reliance on rare earth materials will accelerate. It is anticipated that the shift to next-generation motor technologies, like axial flux motors, which provide great power density in a small package, will quicken. In order to ensure optimal performance across segments, industries will also increasingly concentrate on developing motors specifically designed for specialised EV applications, such as driverless vehicles, two-wheelers, and heavy-duty trucks.

Social acceptance of EVs and related motor technologies will be contingent upon further cost reductions and accessibility enhancements. Policies that support clean energy and mobility, like financing for research into sustainable motor technology and incentives for EV adoption, will be essential. Public support and a move away from internal combustion engine vehicles towards Electric Vehicles (EVs) can be generated *via* educational efforts that emphasise the economic and environmental advantages of EV motors. Achieving fair mobility solutions will need to ensure global access, especially in developing nations.

EV motor development is at the nexus of industrial adaptability, technological innovation, and societal change. Performance gains will be fuelled by scholarly research into improved materials, motor architectures, and control systems. Manufacturers are in a good position to concentrate on sustainability, cost reduction, and scalability. The adoption rate will be influenced by social factors such as public knowledge, policy backing, and equal access. The next stage of EV motor development will be shaped by the joint efforts of manufacturers, researchers, and legislators, paving the way for cleaner, more sustainable, and efficient transportation in the future.

**Chapter 3**, "Field Oriented Speed Control of BLDC Motor for Practical Drive Cycle", discusses how in Electric Vehicle (EV) applications, Field-Oriented Control (FOC) for brushless DC (BLDC) motors has emerged as a component for attaining accurate speed and torque control. Understanding the mathematical modelling, vector control concepts, and real-world application of FOC has advanced significantly from an academic standpoint. Studies have indicated that FOC enables the separation of torque and flux components, resulting in improved dynamic performance under variable drive cycles, smoother operation, and increased efficiency. However, issues like sensor accuracy, computational complexity, and

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