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Design and Simulation of a Dynamic Electric Vehicle Charging System Using Adaptive Control Techniques

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Abstract:
Electric Vehicles (EVs) need regular charging to run, but stopping and plugging them in can be slow and uncomfortable for drivers. To solve this problem, this project introduces an Automatic Dynamic Wireless EV Charging System, which can charge an EV while it is moving without using any cables. The idea works like wireless mobile charging but on a bigger scale. A special coil placed under the road creates a magnetic field when it is powered by a high-frequency circuit. When the EV drives over this area, another coil fixed under the vehicle receives this energy, changes it into usable electricity, and sends it to charge the battery. To make the system safe, it turns on only when a vehicle enters the charging zone, preventing waste of energy. The complete system is tested using MATLAB/Simulink, which shows that the output voltage starts with a small jump and then smoothly increases with time. This smooth increase proves that the charging process is stable and controlled. The waveforms also show no big distortions, meaning the system works cleanly and reliably. Overall, this project shows a smart and modern way to charge EVs without stopping, helping reduce range anxiety and supporting future smart-road technologies.

Keywords: Electric vehicle charging, dynamic charging system, adaptive control techniques, DC–DC power converter, battery charging control, state-of-charge estimation, energy management system, load-adaptive control, MATLAB/Simulink simulation, performance analysis.

I.INTRODUCTION

The rapid growth of Electric Vehicles (EVs) has created a strong demand for efficient, reliable, and convenient charging technologies. EVs are widely recognized as a sustainable alternative to conventional internal combustion engine vehicles because they reduce greenhouse gas emissions, lower fuel dependency, and support clean energy adoption. However, one of the major challenges that still limits large-scale EV adoption is the availability and inconvenience of charging infrastructure. Traditional plug-in charging requires vehicles to stop for long durations, which increases waiting time, reduces travel flexibility, and causes range anxiety among drivers. Therefore, there is a strong need for advanced charging solutions that enable faster, seamless, and user-friendly energy replenishment. Wireless Power Transfer (WPT) has emerged as a promising technology to overcome these limitations. WPT systems eliminate the need for physical cables and enable safe, contactless energy transfer using electromagnetic induction or resonant magnetic coupling. Recently, Dynamic Wireless Charging (DWC) has gained significant attention, where electric vehicles can be charged while moving on specially designed roads. In this method, transmitter coils embedded beneath the road generate a high-frequency magnetic field, and receiver coils mounted under the vehicle capture this energy to charge the battery. Such systems reduce charging downtime, extend driving range, and improve overall convenience for EV users. Several researchers have contributed to the development and improvement of dynamic wireless charging systems. Shanmugam et al. provided a comprehensive review of DWC technologies, including charging couplers, compensation networks, converters, and control circuits, along with grid-connected and photovoltaic-integrated designs. Researchers from Tongji University demonstrated an 11-kW system with an LCC-SP compensation network, achieving high efficiency even under coil misalignment. Rahul Kumar et al. analyzed various inductive pad geometries and highlighted challenges such as leakage flux, misalignment, and electromagnetic interference that affect power transfer efficiency. Other studies have focused on improving system performance through impedance matching, better compensation techniques, and multi-coil configurations. In addition to hardware design, smart control and energy management strategies play an important role in maintaining grid stability. Elghanam et al. proposed real-time coordination algorithms for allocating EVs to optimal charging lanes, while Cheng et al. introduced smart charging algorithms to balance grid load without using energy storage systems. Forecasting and planning approaches have also been explored to predict charging demand and optimize charging station placement. These studies indicate that combining efficient power transfer with intelligent control is essential for reliable large-scale deployment of EV charging infrastructure.Despite these advancements, many existing charging systems still require stationary charging or complex infrastructure. Therefore, implementing a practical and efficient dynamic wireless charging model remains an important research area. In this context, the present project proposes an Automatic Dynamic Wireless EV Charging System that enables contactless charging while the vehicle is in motion. The system uses inductive power transfer between road-embedded transmitter coils and vehicle-mounted receiver coils, along with controlled activation to reduce energy loss. The complete design is modeled and simulated using MATLAB/Simulink to analyze voltage characteristics, stability, and charging performance.The proposed system aims to provide a smart, safe, and reliable solution that minimizes charging interruptions, reduces range anxiety, and supports the development of future intelligent transportation systems. By integrating wireless charging with automated control and efficient power transfer, this project contributes toward building sustainable and next-generation EV infrastructure.

II.LITERATURE REVIEW:

The author Y. Shanmugam and co-authors presented a systematic review of Dynamic Wireless Charging (DWC) technologies, covering charging couplers, compensation networks, power converters, sensing circuits, and controller units. The paper also discusses grid-tied and PV-integrated DWC systems and provides design flowcharts and case studies for various power levels Tongji University Researchers. An 11-kW dynamic charging system using an LCC-SP compensation network with a secondary current doubler was developed to improve power transmission efficiency. The system achieved 91.286% efficiency even under horizontal misalignment and reduced higher-order harmonics**[1].** The author Elhanan et al. (2022) proposed an advanced coordination strategy for managing the charging demand of Electric Vehicles (EVs) in a network of Dynamic Wireless Charging (DWC) systems. The authors highlighted that dynamic wireless charging enables EVs to charge while moving, which significantly reduces range anxiety and eliminates charging downtime. However, they emphasized that without proper coordination, large-scale EV charging can cause grid overload, voltage fluctuations, and peak demand issues. To address these challenges, the study introduced an online, mobility-aware spatial allocation algorithm that assigns EVs requesting charge to the most optimal DWC lanes. Unlike traditional offline or day-ahead scheduling methods, their approach operates in real time using an edge-aggregator based coordination framework. The system considers parameters such as EV location, state of charge (SoC), travel distance, grid supply capacity, and lane energy availability to ensure balanced power distribution**[2].**The author Rahul Kumar J., Narayanamoorthi R., Pradeep Vishnuram, Mohit Bajaj, Vojtech Blazek, Lukas Prokop, and Stanislav Misak (2023).Rahulkumar et al. presented a comprehensive empirical survey on Wireless Resonant Inductive Power Transfer (WRIPT) and Dynamic Wireless Power Transfer (DWPT) systems for in-motion electric vehicle charging. The authors analyzed inductive power pad design, resonant magnetic coupling circuits, and parameters influencing Power Transfer Efficiency (PTE). They compared different pad geometries such as DD, DDQ, and bipolar structures and highlighted challenges including misalignment, leakage flux, interoperability, and EMI shielding. The study also discussed optimization techniques and future research directions for improving wireless charging performance .2. Brown (1963) demonstrated one of the earliest practical microwave wireless power transmission systems. His work validated the concept of transferring electrical energy without physical connections and laid the foundation for modern wireless power technologies**[3**]. The author Peng et al. (2022) proposed a spatio-temporal dynamic forecasting model called DCC-2D (Dilated Causal Convolution-2D neural network) to predict electric vehicle (EV) charging load considering both time and spatial variations. The model uses dilated causal convolution to capture long-term temporal dependencies and 3D convolution to extract spatial features from charging station distributions. Experimental results showed that DCC-2D outperformed ConvLSTM with lower MAE and RMSE, achieving higher prediction accuracy for short-term EV charging demand. Mathematical & Queuing Based Models.Bae and Kwasinski (2012) developed a spatial and temporal charging demand model using traffic flow and probabilistic behavior analysis to estimate EV charging requirements[4]. The author Jin, Acquah, Seo, and Han (2024) proposed a stochastic power flow (SPF)-based framework for optimal siting and sizing of EVCSs. Their method incorporates probabilistic EV charging loads and introduces a Dynamic System Voltage Stability (DSVS) index. The model simultaneously optimizes operator profit, user convenience, and grid stability using SEDEA weighting and an adaptive differential evolution algorithm, demonstrating improved voltage stability and planning robustness compared with deterministic and two-point estimation approaches**[5].** The author Ren et al. (2025) Ren, Liu, Tan, Su, and Li proposed a robust scheduling framework for EV charging stations that addresses uncertainties in real-time electricity prices and stochastic EV charging demand. The authors introduced an ensemble prediction–probability mapping method to model price volatility and designed a risk-aware dynamic subsidy mechanism to encourage station participation in demand response. They further developed a distributionally robust optimization (DRO) model with a hybrid ambiguity set combining moment-based and Wasserstein distance metrics to handle demand uncertainty. Their approach improved cost efficiency, robustness, and grid stability under uncertain conditions .Tan et al. implemented Time-of-Use (TOU) pricing strategies to shift EV charging to off-peak hours, reducing grid congestion. However, their fixed pricing structure lacked adaptability to short-term market fluctuations, limiting real-time performance**[6].** The author Cheng et al. (2021),Qifu Cheng, Lei Chen, Qiuye Sun, Rui Wang, Dazhong Ma, and Dehao Qin, “A Smart Charging Algorithm Based on a Fast Charging Station Without Energy Storage System,” CSEE Journal of Power and Energy Systems, 2021.This work proposes a DC fast charging station (FCS) architecture that operates without an energy storage system (ESS) to reduce installation and maintenance costs. The authors introduce a Smart

Charging Algorithm (SCA) consisting of:The system dynamically redistributes EV charging power based on State of Charge (SOC) and uses adaptive droop control to balance grid power fluctuations. Simulation and experimental results show improved grid stability, better converter utilization, and cost reduction. Núñez et al. (2020) developed a facial recognition-based attendance system using Artificial Neural Networks (ANN) and Raspberry Pi. The system automatically identifies individuals and records attendance, improving reliability and reducing manual errors.**[7].**The author Núñez et al. (2020)Núñez and colleagues developed a facial recognition–based attendance system using artificial neural networks and Raspberry Pi. Their system automatically identifies employees through image capture and classification techniques. Experimental results showed high identification accuracy and reduced manual errors, demonstrating that biometric approaches can effectively replace traditional attendance methods. Espinosa et al. (2019) proposed a face recognition timekeeping system for workforce management in a fruit exporting company. The system automated employee check-in/out processes and integrated attendance data directly into payroll software. The study reported improved payroll accuracy, reduced proxy attendance, and increased productivity, confirming the practicality of automated attendance systems in industries**[8].**The author Khan and Ahmad (2022) proposed a photovoltaic (PV)-integrated fast-charging station model optimized for smart grid interaction. Their study demonstrated that PV-supported charging can significantly reduce peak grid demand and improve energy sustainability. Guo and Maleki (2020) applied queuing theory combined with genetic algorithms to determine optimal charger placement. Their results highlighted the trade-off between infrastructure investment cost and service quality, showing that intelligent planning reduces waiting times while minimizing expenses**[9].**The author Ramakrishnan et al. (2024) presented a comprehensive review focusing on efficiency enhancement techniques for WPT-based EV charging systems. The authors analyzed critical factors affecting PTE such as coupling coefficient, quality factor, coil alignment, air gap, impedance matching, and compensation networks. They emphasized impedance matching, compensation topologies, and multi-transmitter configurations as key strategies to improve system efficiency and reliability. Patil et al. reviewed wireless EV charging pads, compensation topologies, standards, and impedance matching techniques. Their study highlighted challenges in dynamic WPT systems, including high installation cost, electromagnetic field exposure, and communication limitations, concluding these factors restrict large-scale deployment**[10].**

III.SYSTEM MODULE

EXISTING SYSTEM:

The existing electric vehicle charging system is primarily based on static, plug-in charging units that are directly connected to the electrical grid. These chargers operate when the vehicle is stationary and employ power electronic interfaces, typically consisting of an AC–DC rectifier followed by a DC–DC converter, to regulate the charging power supplied to the battery. In conventional power system studies, such EV chargers are modeled as static loads using constant power, constant current, or constant impedance representations to analyze their steady-state impact on voltage profiles, power flow, and harmonic performance. However, this approach does not account for the dynamic interaction between the charger and the power system under varying operating condition.

DISADVANTAGES:

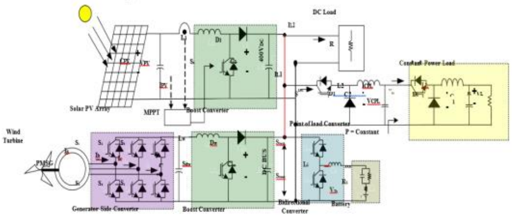
•Converter efficiency is low
•Reduced wireless efficiency

- Poor performance of non-resonant IPT systems
- Inconsistent renewable energy supply
- Heat generation is more
- Connector issues in wired charging

PROPOSED SYSTEM:

The proposed system is a compact, The proposed Automatic Dynamic Wireless EV Charging System aims to enhance the efficiency, safety, and adaptability of wireless charging for moving electric vehicles using MATLAB simulation. The system employs transmitter coils embedded in the road and receiver coils mounted under the EV, enabling dynamic charging while in motion with automatic coil detection to minimize misalignment losses. An LCC-LCC resonant compensation network reduces voltage ripple, switching losses, and current spikes, maintaining high efficiency even under variable load or air gap conditions. The system integrates multiple power sources, including grid, solar, and wind energy, promoting eco-friendly charging and reducing grid dependency. An intelligent control system dynamically adjusts operating frequency and voltage to ensure maximum power transfer efficiency while monitoring battery temperature and load to prevent overheating. Optional bidirectional power flow allows vehicle-to-grid (V2G) energy feedback when required. Comprehensive safety features, including overcurrent, overvoltage, and thermal protection, prevent battery degradation and enhance user safety. MATLAB simulations validate the system's performance, with output waveforms showing voltage rise and stabilization, and the capability to model dynamic vehicle movement, coil misalignment, and various power sources.

Block diagram of automatic dynamic ev charging system



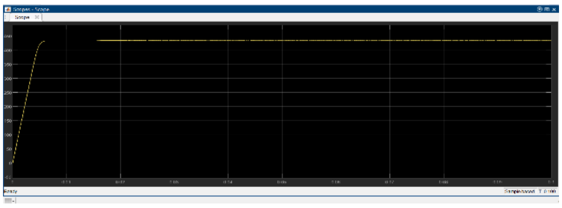
ADVANTAGES:

- Dynamic Charging Capability
- High Efficiency
- Reduced Misalignment Losses
- Renewable Energy Integration
- Intelligent Control

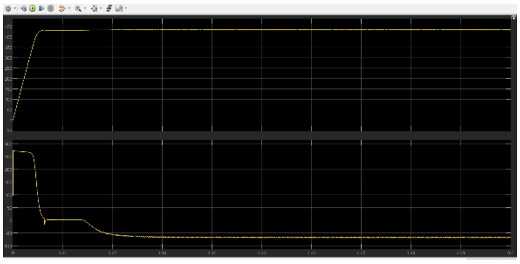
SOFTWARE REQUIREMENTS:

- Coding language: Mat lab 2024a version

IV.RESULT



The given graph represents the output voltage response of a system with respect to time, obtained from a simulation scope (MATLAB/Simulink). Initially, the output voltage starts from zero and shows a rapid rise, reaching a steady value of approximately 440–450 V within a very short duration. After this transient period, the voltage remains almost constant, indicating steady-state operation.



The top waveform represents the DC-link or output voltage**.** It rises rapidly from zero and settles at around 440–450 V within a short time. The bottom waveform represents the current response of the system. Initially, a high inrush current is observed due to capacitor charging or sudden load connection. The combined voltage and current responses confirm that the system is stable, well-controlled, and efficiently regulated**.**

V.CONCLUSION:

We concluded that Automatic Dynamic Wireless EV Charging System successfully demonstrates an efficient and intelligent method for charging electric vehicles while in motion, thereby reducing range anxiety and eliminating the need for frequent charging stops. The system's automatic vehicle detection and controlled power-transfer mechanism ensure safe, continuous, and optimized energy delivery to the EV. By enabling on-road wireless charging, the project enhances the practicality, reliability, and scalability of EV technology. This innovation supports the widespread adoption of electric vehicles and represents a promising step toward future sustainable and smart transportation infrastructure.

FUTURE SCOPE:

In the future, the project will focus on enhancing the system’s performance through hardware implementation of the dynamic wireless charging setup using Inductive Power Transfer (IPT) coils. The design will be optimized to improve charging efficiency, coil alignment tolerance, and thermal management during high-power transfer. Integration with renewable energy sources such as solar and wind will be expanded, along with a smart energy management unit for real-time control. Further work will include simulation refinement in MATLAB/Simulink and the development of an IoT-based monitoring system for tracking energy flow, vehicle status, and charging conditions remotely. Long-term goals include field testing, cost optimization, and ensuring compatibility with multiple EV models to promote large-scale adoption of the technology.

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