



Integration Of Electric Vehicle With Microgrid

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Abstract: The integration of Electric Vehicles (EVs) as sustainable energy systems offers dual benefits of enhanced grid stability as well as optimized energy utilization[1]. This research paper examines the bidirectional relationship between EVs and microgrids, focusing on charging strategies, grid impact analysis, and optimization techniques. This paper presents the design, implementation, and testing of a hardware prototype for integrating electric vehicles with microgrids using rooftop solar power. The proposed system utilizes a microcontroller-based control architecture with an inverter and step-up transformer to manage bidirectional power flow between EVs and the microgrid. The prototype demonstrates effective charging management, solar integration, and grid support capabilities through a Battery Management System (BMS) and bidirectional energy conversion. This study presents innovative solutions for seamless EV-microgrid integration while maintaining grid stability and maximizing renewable energy utilization. Experimental results show successful implementation of controlled charging strategies and solar power utilization, achieving improved grid stability and efficient energy management[7].

Index Terms - Electric vehicle (EV), Vehicle to grid (V2G), Grid integration, grid stability, Grid to vehicle (G2V), Bidirectional Charging, Battery Management System (BMS)

I. INTRODUCTION

The global transition towards sustainable means of transportation has accelerated the electric vehicle adoption, creating new opportunities and challenges for the power distribution systems. Microgrids, as localized energy networks capable of operating independently or in conjunction with the main grid, present a promising solution for managing EV charging loads while maintaining system reliability.

The integration of electric vehicles (EVs) into microgrids represents a critical step in sustainable energy systems. This project implements a hardware prototype to demonstrate the practical feasibility of bidirectional power flow between EVs and microgrids, with additional solar power integration. The system addresses key challenges in EV charging infrastructure while providing grid support capabilities through intelligent power management and control strategies.

Current challenges in EV-microgrid integration include power quality issues, charging coordination, and renewable energy integration[9]. This prototype specifically addresses these challenges through a microcontroller-based system that manages power flow, charging processes, and solar energy utilization, providing a practical solution for small-scale implementations such as residential and commercial applications. This project builds upon existing research while introducing practical improvements in control strategy and system integration.

II. OBJECTIVES

Recent advancements in EV sector have focused on bidirectional power flow capabilities and renewable energy integration. Studies show that incorporating solar power with EV charging can reduce grid dependency by 30-40% while providing additional benefits for grid stability. Key developments in power electronics, particularly in the inverters, and, solar charging technologies, have enabled more efficient and reliable integration solutions. This research project primarily aims to develop and implement a functional hardware prototype demonstrating the integration of electric vehicles with microgrids through rooftop solar power integration[3]. This overarching goal encompasses several specific technical objectives aimed at creating a practical and efficient system. The prototype seeks to demonstrate the feasibility of bidirectional power flow between EVs and microgrids while incorporating renewable energy sources, specifically through rooftop solar integration.

This implementation aims to address real-world challenges in EV charging infrastructure and grid stability. A crucial objective is the development of an intelligent control system based on microcontroller architecture. This system must efficiently manage power flow between multiple sources and loads while maintaining system stability and ensuring safe operation.

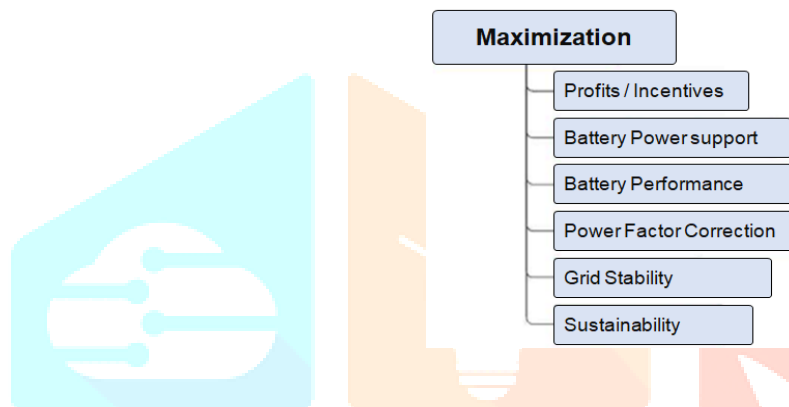


Fig. 1: Objective Function of Maximization in V2G

The system needs to handle both steady-state operation and transient conditions, implementing protective measures to prevent system damage and ensure reliable operation under various operating conditions.

The project further aims to optimize the energy transfer efficiency through advanced power electronics implementation. This includes the design and implementation of an inverter system capable of managing bidirectional power flow with minimal losses. The optimization extends to the integration of solar power through appropriate system, ensuring optimal utilization of available renewable energy resources.

Another significant objective is the implementation of a comprehensive Battery Management System (BMS) that ensures safe as well as efficient operation of battery while maximizing battery life. This system must monitor and control various parameters including cell voltage, temperature, and state of charge, implementing appropriate protection mechanisms when necessary[5]. The BMS needs to communicate effectively with the main control system to ensure coordinated operation of all system components. Previous implementations have demonstrated various approaches to EV-microgrid integration, but few have combined rooftop solar integration with bidirectional charging capabilities in a compact, cost-effective prototype.

2.1 Evolution of EV-Microgrid Integration

The concept of integrating EVs with microgrids has evolved significantly over the past decade. Early research focused primarily on unidirectional charging management, while recent developments emphasize bidirectional power flow capabilities.

2.2 Current State of Technology

Modern EV-microgrid integration encompasses:

- Smart charging infrastructure
- Energy management systems

2.2.1 Power Electronics Architecture

Modern EV-microgrid integration relies on sophisticated power electronics. Key components include:

1. Inverter

- Type: MOSFET-based
- Control: Grid synchronization
- Power Rating: 200 W

2. Battery Management System

- Current Rating: 40 A (maximum)
- Voltage Rating: 12.6 V to 14.2 V DC

2.3 Various Opportunities

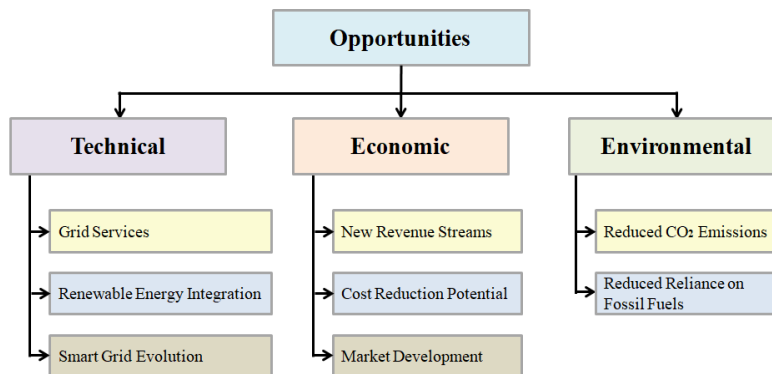


Fig. 2: Various Opportunities in EV-Microgrid Integration

III. METHODOLOGY

The implementation methodology for the proposed project utilizes bidirectional charging scheme in the EV technology. Here, two methods of charging the electric vehicles have been proposed, the primary being the solar charging system, while the secondary being the conventional method of charging through the electric supply, that is, G2V or grid-to-vehicle technology. For the solar charging, a Pulse Width Modulated- solar charge controller is used. This controller regulates charging process of batteries in photovoltaic (PV) systems by adjusting the width of the pulses sent to the battery, ensuring efficient and safe charging.

3.1 System Design Approach

The development methodology follows a systematic approach beginning with comprehensive system analysis and design. Initial analysis focuses on two different power requirements, considering both the EV charging needs and microgrid capabilities. This phase involves detailed analysis of power ratings, voltage levels, and current requirements for all major components. The design process incorporates previous simulation studies and researches to validate the system concept before hardware implementation.

Component selection follows rigorous criteria based on the calculated requirements and safety margins. This includes selecting appropriate semiconductor devices for the inverter (such as MOSFET), determining transformer specifications, and choosing a microcontroller with adequate processing capability and peripheral features.

The methodology emphasizes practical considerations such as component availability, cost-effectiveness, and reliability while maintaining the required performance specifications.

3.2 Implementation Strategy

The hardware implementation follows a modular approach, with each major subsystem developed and tested independently before system integration. This strategy begins with the development of the control system, implementing the necessary firmware for the microcontroller to manage system operation. The system is first tested using power sources to verify proper operation before connecting to actual power components.

Power electronics implementation forms a critical part of the methodology, focusing on the inversion stages. This includes design with consideration for factors such as thermal management, cost reduction, and protection circuits. The implementation includes extensive testing of power conversion efficiency, thermal performance, and electromagnetic compatibility.

3.3 Testing and Validation Framework

The testing methodology encompasses both component-level and system-level validation. Each subsystem undergoes rigorous testing under various operating conditions to ensure reliable operation. This includes:

- Power conversion efficiency measurements
- Thermal performance evaluation
- Control system response testing
- Protection system verification
- Long-term reliability assessment

IV. HARDWARE REQUIREMENTS

The project hardware consists of the following components:

- Arduino UNO
- DC Gear Motor
- Motor Speed Controller
- 16x2 LCD Display
- BMS
- 2-Channel Relay Module
- Rectifier & Filter Circuit
- Transistor
- Transformer (step-up)
- Solar Panel (10W)
- Battery Pack
- PWM Solar Charge Controller
- Inverter Board
- Connecting wires
- Power supply (220 V AC)
- A Microgrid Load

4.1 Control System Architecture

The control system centers around a high-performance microcontroller that serves as the brain of the entire system. The selected microcontroller should provide adequate processing power and peripheral features including PWM solar charge controller & analog inputs for measurements. For this implementation, we utilize a 32-bit microcontroller. The control system design incorporates necessary protection features. This includes voltage and current sensing circuits.

4.2 Power Electronics Implementation

4.2.1 Inverter

The inverter represents a critical component in enabling bidirectional power flow. This full-bridge configuration utilizes four high-frequency MOSFETs with integrated gate drivers, designed to handle the required voltage and current levels efficiently. The design incorporates heat sinks to manage switching transients and thermal loads effectively. Specific features include:

- Input voltage: 12 V DC
- Integrated protection features
- Power output: 200 W
- Output Frequency: 50Hz-60Hz
- Efficiency > 95%

4.2.2 Step-up Transformer

The transformer design balances efficiency with practical considerations of size and cost. Key specifications include:

- Primary voltage: 12 V AC
- Secondary voltage: 230V AC
- Frequency: 50Hz
- Efficiency > 97%

- Temperature rise $< 40^{\circ}\text{C}$

4.3 Battery Management System

The BMS implementation encompasses comprehensive battery monitoring & protection features. The system continuously monitors cell voltages, current, & temperature while implementing cell balancing. Key features include:

- Individual cell voltage monitoring (0-5V per cell)
- Temperature monitoring (-20°C to $+60^{\circ}\text{C}$)
- Current monitoring ($\pm 100\text{A}$)
- 4-cell BMS is used.
- Cell balancing capability
- Interface with main controller
- Protection against over-current, over-voltage, & over-temperature

V. BLOCK DIAGRAM

The system architecture illustrated in the block diagram demonstrates the integration of multiple subsystems working together to achieve efficient FV-microgrid integration. Each component plays a specific role in the overall system operation

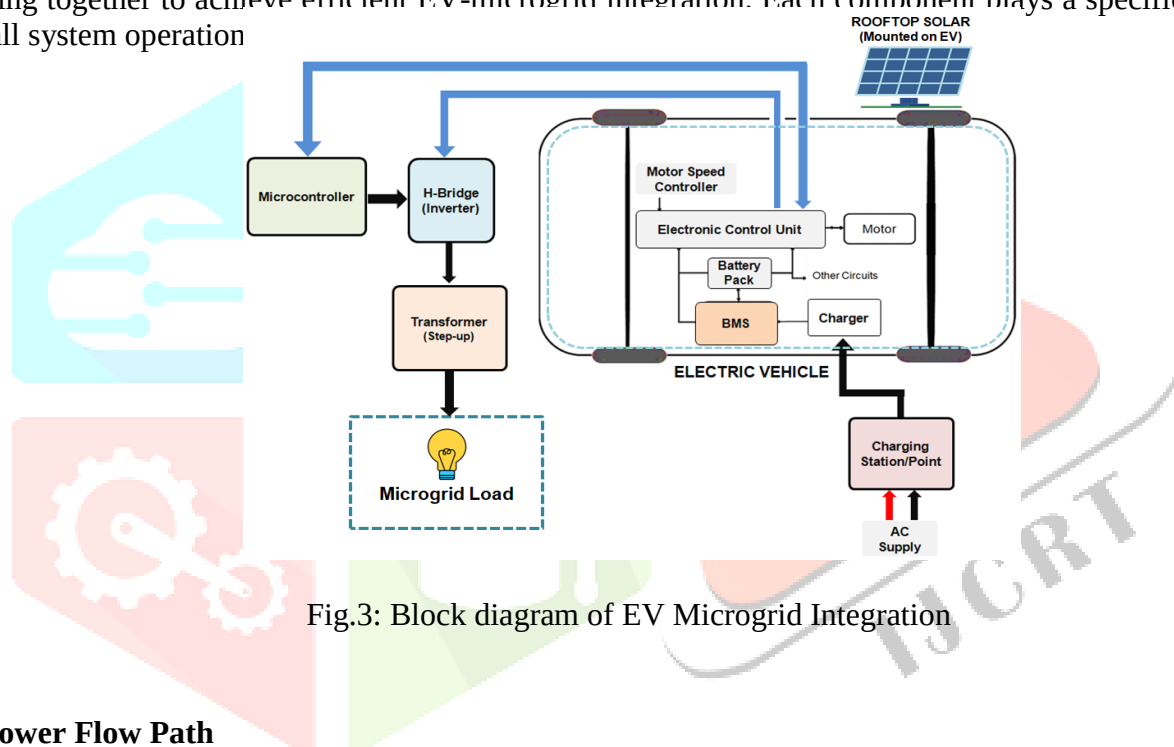


Fig.3: Block diagram of EV Microgrid Integration

5.1 Power Flow Path

The primary power flow path begins with the AC supply input to the charging station, which connects to the EV's onboard systems. The charging circuit incorporates necessary protection and power conditioning circuits, ensuring safe and efficient power transfer. Within the EV, the power flow is managed through multiple stages:

The Electronic Control Unit (ECU) serves as the primary interface between the vehicle's systems and the charging infrastructure. It manages the charging process while communicating with the BMS and other vehicle systems. The BMS monitors the battery-performance and provides protection. The motor speed controller serves as the control mechanism for controlling the motor speed by varying the voltage and current.

5.2 Solar Integration

The rooftop solar integration provides an additional power source, feeding into the system through appropriate power conditioning circuits. This renewable energy source helps to reduce grid dependency while providing supplementary charging power. The solar integration includes:

- Conversion for voltage matching
- Protection circuits
- Integration with main control system

5.3 Control and Communication

The motor speed controller is employed in the system that controls the motor by varying the speed. Also, the PWM solar charge controller has been employed for controlling the charging activity of the battery pack. The specifications of the PWM solar charge controller are as follows:

- Voltage: 14.2 V
- Rated charging current: 10A-30A

The microcontroller-based control system has various functions such as: power flow management, communication with vehicle systems, monitoring and protection, user interface control as well as data logging and system diagnostics.

VI. EV CHARGING STRATEGIES

6.1 Uncontrolled Charging

Uncontrolled charging, also known as uncoordinated or dumb charging, represents the most basic approach to EV charging implementation within microgrid environments. In this conventional charging method, vehicles begin charging immediately upon connection to the charging station, drawing maximum available power until the batteries get fully charged or until the charging session is manually terminated by the user. While this approach offers simplicity and user convenience, the analysis of uncontrolled charging patterns reveals that peak demand coincides with existing grid peak loads, particularly during evening hours when EV owners return home and plug-in their vehicles for charging. Such synchronization of charging loads with existing peak demands can lead to substantial strain on grid infrastructure.

The implementation costs associated with uncontrolled charging extend beyond immediate infrastructure requirements. Historical data from multiple urban deployments indicates that uncontrolled charging can increase local peak loads by 25-40%. This increased demand not only affects infrastructure requirements but also impacts electricity costs.

6.2 Smart Charging

Smart charging represents a significant advancement in EV charging strategy, incorporating solar charging mechanism and battery management system to optimize charging patterns based on multiple parameters. This approach, also known as coordinated or intelligent charging, enables dynamic adjustment of charging power and timing to balance vehicle owner requirements with grid constraints and opportunities [8]. The implementation of smart charging systems typically involves advanced metering infrastructure & two-way communication capabilities that can respond to various inputs including electricity prices, grid conditions, renewable energy availability, and user preferences.

Time-of-use (TOU) based charging, is a fundamental component of smart charging strategies that enables vehicle charging time to be shifted to periods of lower grid demand or higher renewable energy generation. Studies have shown that the implementation of smart charging can reduce charging costs by 15-30%. Renewable energy-aligned approach has proven particularly effective in microgrids with significant solar or wind generation capacity. The data from existing systems shows that renewable energy utilization can be increased by 25-40% through intelligent charging coordination, thereby achieving a significant reduction in the carbon footprint of EV charging operations while improving the economic viability of renewable energy installations [4].

6.3 Vehicle-to-Grid (V2G) Implementation

Vehicle-to-Grid technology is regarded as the most advanced form of EV-microgrid integration, enabling bidirectional power flow between vehicles and the grid infrastructure. This sophisticated approach transforms EVs from mere loads into distributed energy resources capable of providing various grid services [4]. The technical implementation of V2G systems requires specialized hardware including bidirectional inverters, and communication systems capable of managing both power flow directions while ensuring battery health and user mobility requirements are maintained.

The system facilitates the exchange of critical parameters including available battery capacity, power limitations, pricing signals, and grid service requests. Implementation experience has shown that successful V2G deployments require communication latencies below 100ms for primary frequency response services. Battery degradation considerations play a crucial role in V2G implementation strategies. Research indicates that while V2G operations can accelerate battery wear, proper management strategies can minimize this

impact. Factors such as battery temperature, state of charge, and cycling depth have demonstrated the ability to reduce degradation impacts by 40-60% compared to unmanaged V2G operation. Economic analysis of V2G implementations shows that despite potential battery degradation costs, the revenue generated from grid services can provide a net positive return on investment, with typical payback periods ranging from 3 to 5 years depending on market conditions and service provision opportunities.

VII. EV OPTIMIZATION TECHNIQUES

The term "bidirectional V2G" means the dual direction flow of power between the EVs and electrical power grid in order to achieve the stability of the power grid. The G2V strategy has some advantages over the bidirectional charging, which includes less battery degradation, lower costs and initial investments, simpler control along with fewer social barriers. The premium services that can be provided by bidirectional charging along with the providing the beneficiaries to the grid also imposes challenges such as battery degradation in EVs and voltage limit, generation limit, thermal line limit and system loading in grid.

VIII. RESULT

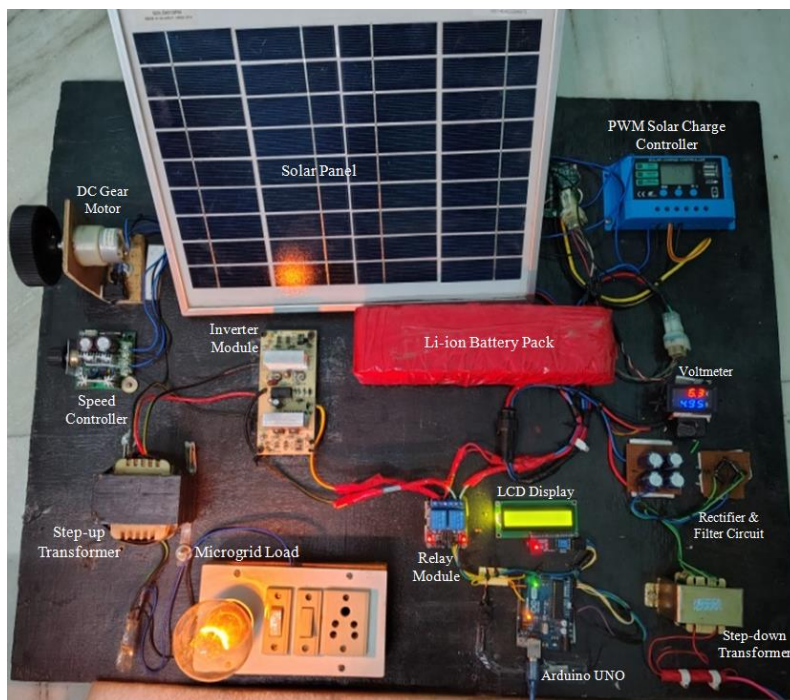


Fig. 4: Working model of the project Voltmeter



Fig. 5: Message on LCD Display



Fig. 6: DC Voltage generated from solar cell displayed on the PWM Solar Charge Controller



Fig. 7: AC Voltage obtained on the

Experimental results from the prototype implementation demonstrate the following results:

- Finally, the designed prototype was able to achieve a voltage range between 220 V to 260 V AC, with frequency range between 50 to 60 Hz. This voltage thus obtained, can be further stepped-up to further higher voltages to be utilized into electricity grids using the advanced systems and synchronization methods.
- The employment of the solar panel generated a dc voltage ranging between 14.4V to 19 V.
- The introduction of BMS in the system improved the efficiency of the system, by continuously monitoring the battery performance. When the battery charging voltage was reached upto 90%, the system was manually switched to reverse charging mode (depending upon the requirement of the consumer). When needed, the system is utilized to run the household loads according to the consumer flexibility.

Impact of the implemented project on the Microgrid:

- Peak load was reduced through controlled charging due to the employment of the EV battery as the distributed energy resource, which stored the energy in the battery, and delivers energy when required.

- Active customer participation in the grid is achieved due to the reliability of the customer on the EV during the peak hours of the day instead of depending on the grid. This will reduce the stress on the electrical grid during the peak hours of the day.
- Also, the deployment of the solar panel as a primary source of charging for the EV was profitable in a few ways as- reduced reliance on the grid during peak hours will reduce the electricity bills and sustainable source of green energy.

IX. CONCLUSION

The implemented hardware prototype successfully demonstrates the feasibility of integrating EVs with microgrids using solar power. The system was able to achieve efficient bidirectional power flow, effective battery management, and successful solar energy integration. The results validate the design approach and suggest suitable potential for scaling to larger implementations. Future improvements could focus on enhanced control and additional renewable energy sources such as wind. Also the concept of regeneration can be utilized at larger scale to improve the efficiency of the system.

In this paper, various aspects of electric vehicle-grid integration in both V2G and G2V mode of EVs are studied. Different types of existing charging and discharging strategies of EVs are reviewed.

The centralized control framework aims at providing optimal charging schedule for EVs by keeping grid constraints such as power quality parameters, peak load demand, grid losses in permissible limits. The decentralized control emphasizes on satisfaction and fulfillment of user demand, EV's battery health, price and incentives. Optimization techniques for control for EVs operating in both G2V and V2G mode are studied comprehensively [2]. This paper also addresses the optimization methods and accordingly, objective functions like profit, power quality, load-factor maximization, and the minimization of charging costs, voltage deviation and frequency deviation is achieved by keeping constraints such as voltage, thermal line, generation, charging and discharging rate within permissible limits [6].

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