International Journal of Engineering Research and Science & Technology

www.ijerst.org

ISSN : 2319-5991

Vol. 22 No. 1 (2026)

ijerst.editor@gmail.com

editor@ijerst.com

ISSN 2319-5991 www.ijerst.com
Vol. 22, No. 1, 2026

Peer Reviewed, Referred & Indexed Journal

Research

ENHANCING THE PERFORMANCE OF SOLAR BASED ELECTRIC VECHILE CHARGING SYSTEM USING FUZZY LOGIC CONTROLLER

[1]Rudroju Shiva Kumar, [2]Egurla Madhupriya, [3]Kalva Tharun, [4]Akula Rachana, [5]Bongoni Balaji
[1]Assistant professor, Department of Electrical & Electronics Engineering,
Jyothishmathi Institute of Technology and Science, Karimnagar, Telangana
shivakumarjits@gmail.com ,egurlamadhupriya21@gamil.com , kalvatharun123@gmail.com, akularachana12@gmail.com,bongonibalaji@gmail.com

Abstract
The rapid penetration of electric vehicles (EVs) and renewable energy sources poses significant challenges to grid stability and energy management. Solar-powered bidirectional EV charging systems with grid support capability have emerged as a promising solution to enhance system flexibility and reliability. This paper presents the design and control of a solar-powered bidirectional EV charging circuit operating in Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) modes using a Fuzzy Logic Controller (FLC). The proposed system intelligently manages power flow between the photovoltaic (PV) source, EV battery, and utility grid under varying solar irradiance, load demand, and grid conditions. The fuzzy controller eliminates the need for an accurate mathematical model and ensures smooth mode transition, reduced current stress, and improved power quality. MATLAB/Simulink-based simulation results demonstrate effective charging/discharging control, stable DC-link voltage regulation, and enhanced grid support during peak demand and voltage fluctuations. The proposed control strategy offers a robust and adaptive solution for smart grid–integrated EV charging infrastructures.

Index Terms—Electric vehicle charging, bidirectional converter, fuzzy logic control, vehicle-to-grid (V2G), grid-to-vehicle (G2V), solar photovoltaic systems.

Received: 21-01-2026 Accepted: 25-02-2026 Published: 04-03-2026

I. Introduction

The increasing adoption of electric vehicles (EVs) has significantly impacted modern power systems, necessitating advanced charging infrastructures capable of supporting grid stability and renewable energy integration. Conventional unidirectional EV chargers primarily draw power from the grid, contributing to peak load stress and voltage instability. To overcome these challenges, bidirectional EV charging systems with Vehicle-to-Grid (V2G) capability have gained attention as an effective grid-support solution.

Solar photovoltaic (PV) energy, when integrated with EV charging systems, offers a clean and sustainable alternative to fossil-fuel-based electricity. However, the intermittent nature of solar power and the dynamic behaviour of EV batteries require intelligent control strategies to ensure reliable operation. Traditional PI-based controllers often suffer from performance degradation under parameter variations and nonlinear operating conditions.

Fuzzy Logic Control (FLC) provides a robust and adaptive control framework that does not rely on precise system modelling. Owing to its heuristic decision-making capability, FLC is well-suited for renewable-integrated EV charging systems operating under uncertain conditions. This paper proposes a fuzzy logic–controlled solar-powered bidirectional EV charging circuit capable of seamless G2V and V2G operation while providing grid support services such as peak shaving and voltage regulation.

2. Literature Survey

Electric Vehicle (EV) charging systems interfaced with renewable energy sources and grid support functions have been widely researched over the past decade. The integration of photovoltaic (PV) generation with bidirectional EV chargers provides a sustainable solution for efficient energy use and smart grid stability. This literature survey discusses major contributions on bidirectional EV charging topologies, solar-integration strategies, control techniques such as fuzzy logic and other soft computing methods, and grid support functionalities including Vehicle-to-Grid (V2G) operations.

A. Solar–EV Charging Integration

Photovoltaic-integrated EV charging systems have attracted significant research due to the growing adoption of EVs and solar energy.

- *Kroposki et al.* highlighted the importance of PV-connected EV chargers to reduce grid dependency and CO_2 emissions, emphasizing renewable energy utilization and smart grid operation [1].
- *Han et al.* introduced a PV-based charging architecture that prioritizes solar energy and improves charger efficiency, addressing intermittency challenges through energy management strategies [2].
- *Al-Hadded et al.* investigated PV charging systems with multi-input converters to simultaneously harvest solar energy and grid power, ensuring optimal energy flow [3].

These works underline the need for efficient MPPT (Maximum Power Point Tracking) and energy management to exploit PV energy effectively.

B. Bidirectional EV Charging and V2G Capability

Bidirectional EV chargers enable power flow both from the grid to the EV (G2V) and from the EV back to the grid (V2G), contributing to grid support such as peak shaving and frequency regulation.

- *Sortomme and El-Sharkawi* were among the first to explore V2G frameworks, demonstrating potential benefits such as load leveling and revenue generation [4].
- *Lopes et al.* reviewed V2G operational requirements and impacts on grid stability, highlighting bidirectional converter design as a critical element [5].
- *Yang et al.* developed a bidirectional DC–DC converter with high efficiency and seamless G2V/V2G transition, focusing on power electronics design [6].

These works establish the viability of bidirectional EV chargers for grid services but often with conventional control approaches like PI regulators.

C. Control Strategies for Bidirectional EV Charging

Control techniques greatly influence the performance of bidirectional charging systems, especially under varying load and renewable conditions.

1) Classical Controllers

- *Wu et al.* applied traditional PI control for DC-link voltage regulation and converter duty cycle adjustment, which showed limitations under nonlinear conditions and required fine-tuning [7].
- *Chen et al.* utilized sliding-mode control (SMC) for robust performance, albeit at the cost of increased implementation complexity due to chattering effects [8].

While effective in many scenarios, these methods struggle with nonlinearity, model dependency, and dynamic uncertainties, especially in renewable-integrated systems.

2) Intelligent and Soft Computing Control

Soft computing techniques such as fuzzy logic, neural networks, and genetic algorithms have shown improved adaptability and robustness.

- *Mohan and Reddy* developed a fuzzy logic controller (FLC) for a standalone PV-battery charging system, demonstrating enhanced dynamic response and robustness to irradiance variability [9].
- *Islam et al.* employed FLC in a grid-tied EV charger to manage power flow and support peak shaving, showing improved stability compared to conventional controllers [10].
- *Patel et al.* incorporated ANFIS (Adaptive Neuro-Fuzzy Inference System) for bidirectional power conversion, achieving better transient response and reduced overshoot [11].
- *Li and Blaabjerg* integrated fuzzy logic with MPPT for a PV inverter system to ensure optimal power extraction despite fluctuating solar conditions [12].

These intelligent control strategies outperform traditional methods in dealing with nonlinear dynamics and parameter uncertainties, placing fuzzy logic as a preferred approach for renewable-integrated EV charging systems.

D. Grid Support and Ancillary Services

Beyond charging/discharging, bidirectional EV systems can provide essential grid services.

- *Tan et al.* explored peak load management using V2G-enabled EVs for frequency regulation and demand response, finding significant improvements in grid stability [13].
- *Han et al.* proposed a coordinated control framework for aggregating EVs to deliver voltage support and reactive power compensation [14].
- *Rahbari-Asr et al.* investigated the potential of EVs in mitigating renewable intermittency, emphasizing intelligent control for reliable dispatch [15].

These studies indicate that grid support from EVs requires advanced control frameworks capable of real-time decision-making beyond simple bidirectional power exchange.

E. Identified Research Gaps

Despite the significant advances, several limitations persist in the current literature:

1. Limited Integration of Solar PV with Bidirectional EV Chargers: Most V2G studies focus on grid-connected systems without effective incorporation of PV sources.
2. Insufficient Soft Computing–Based Control:
   While FLC and ANFIS have been used, there is a lack of detailed strategies addressing simultaneous PV utilization, battery SOC, and grid support under dynamic conditions.
3. Lack of Comprehensive Grid Support Analysis:
   Few works provide quantitative evaluation of grid support capabilities (e.g., peak shaving, voltage regulation) in fuzzy logic–controlled PV–EV charging systems.
4. Non-Adaptive Dynamic Control: Traditional FLC implementations lack adaptability to wide-ranging conditions, motivating the need for enhanced soft computing or hybrid control schemes.

F. Positioning of the Proposed Work

This paper addresses the identified gaps by:

- Integrating a solar PV source with bidirectional EV charging for both G2V and V2G operation.
- Employing a Fuzzy Logic Controller (FLC) to manage power flow based on DC-link voltage error and battery SOC, eliminating dependence on precise system modelling.
- Enabling grid support functionality such as peak load mitigation and voltage stabilization through dynamic power exchange.
- Demonstrating the system's performance through simulation results under varying irradiance and grid conditions.

3. System Configuration

The proposed solar-powered bidirectional EV charging system consists of:

- A solar PV array
- DC–DC boost converter for PV voltage regulation
- Bidirectional DC–DC converter interfacing the EV battery
- DC-link capacitor
- Grid-tied bidirectional inverter
- Fuzzy logic–based control unit

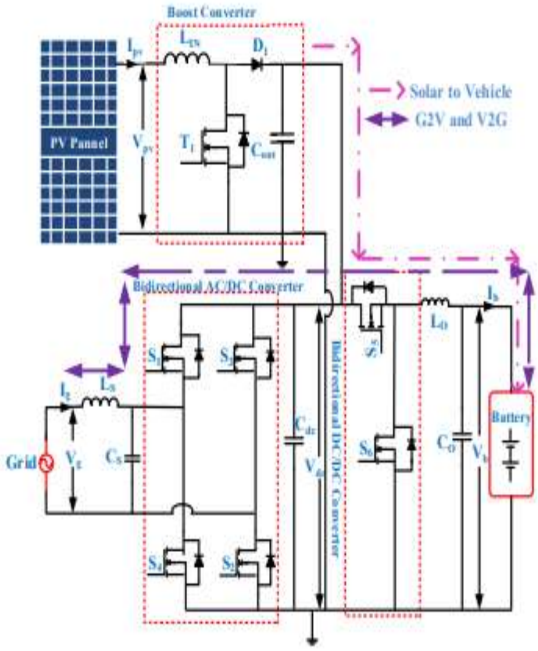


Fig 1. Fuzzy based Solar Charging Configuration for Electric Vehicle

A. Operating Modes

1. **Grid-to-Vehicle (G2V) Mode** In this mode, the EV battery is charged using solar power and/or grid power based on availability and battery state-of-charge (SOC). Priority is given to solar energy to reduce grid dependency.
2. **Vehicle-to-Grid (V2G) Mode** During peak load or grid disturbances, the EV battery supplies power back to the grid, supporting voltage regulation and load balancing.
3. **Solar-to-Grid Mode** Excess PV power is injected into the grid when the EV battery is fully charged.

4. Bidirectional EV Charging Circuit

The bidirectional DC–DC converter plays a crucial role in enabling G2V and V2G operation. It operates in:

- **Buck mode** during EV charging (G2V)
- **Boost mode** during EV discharging (V2G)

The grid-side inverter ensures synchronized power exchange with the utility grid while maintaining unity power factor operation. The DC-link voltage is regulated to ensure stable power flow under all operating conditions.

5. Fuzzy Logic Control Strategy

A. Fuzzy Controller Structure

The fuzzy logic controller consists of:

- Fuzzification unit
- Rule base
- Inference engine
- Defuzzification unit

B. Input and Output Variables

The controller uses:

- **Input 1:** DC-link voltage error
- **Input 2:** Change in DC-link voltage error

Output: Duty cycle adjustment for the bidirectional converter

C. Rule Base Design

A Mamdani-type fuzzy inference system is employed with linguistic variables such as:

- Negative Big (NB)
- Negative Small (NS)
- Zero (ZE)
- Positive Small (PS)
- Positive Big (PB)

The fuzzy rules are formulated to ensure fast dynamic response, reduced overshoot, and smooth transition between G2V and V2G modes.

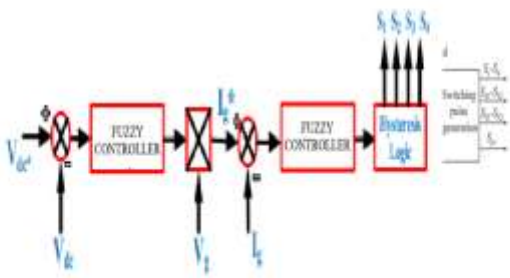


Fig 2.flc based control circuit for ev charging station

6.Grid Support Functionality

The proposed system enhances grid performance by:

- Supplying power during peak demand (V2G)
- Absorbing excess energy during off-peak periods
- Maintaining DC-link voltage stability
- Improving power quality with reduced current harmonics

The fuzzy controller dynamically adjusts power flow based on grid conditions, battery SOC, and solar availability.

7. Simulation Results and Discussion

The system is modelled and simulated in MATLAB/Simulink under varying irradiance and load conditions.

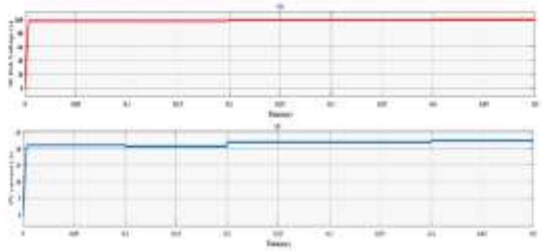


Fig 3. DC link voltage and solar PV Current

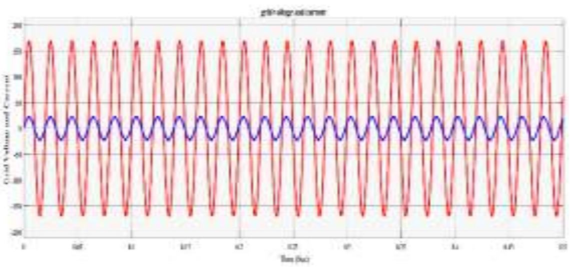


Fig 4. Grid Voltage and Current

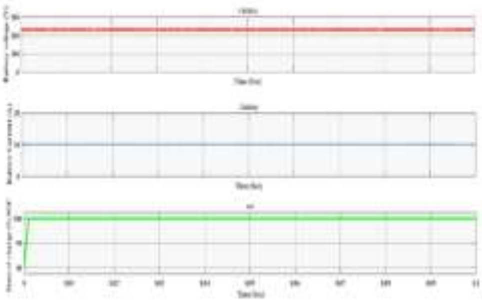


Fig 5. Battery Voltage, Current and SOC

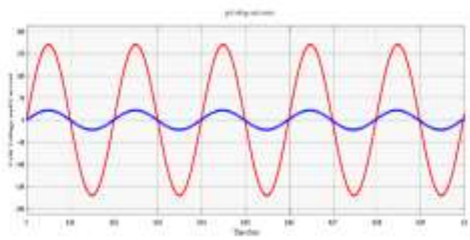


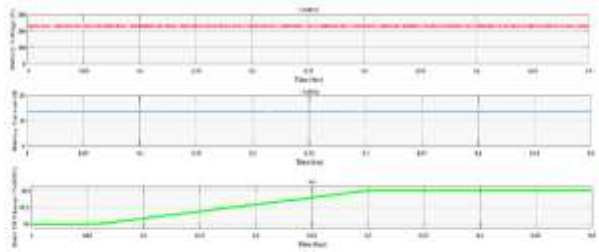
Fig 6. Grid Voltage and Current during charging

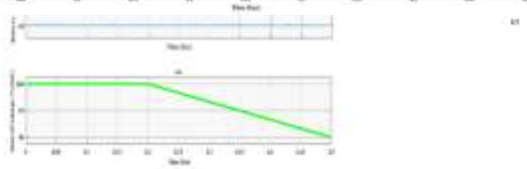
Fig 7. Battery Voltage, Current and SOC during charging

Fig 8. Grid voltage and current during discharging

Fig 9. Battery Voltage, Current and SOC during discharging

Fig 10. THD of the grid voltage is 0.45%





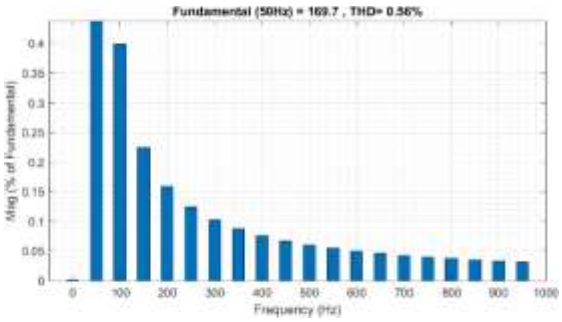
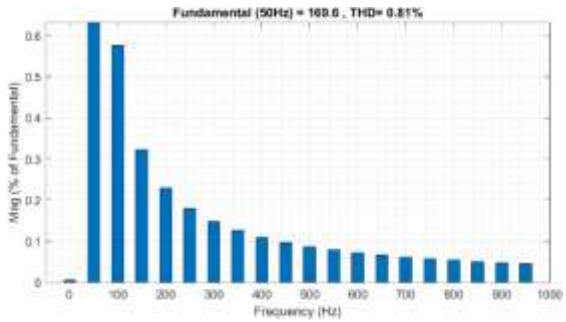


Fig 11. THD of grid voltage during charging is 0.56%



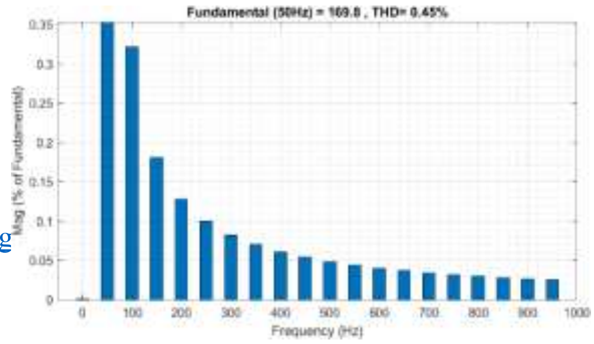


Fig 12. THD of grid voltage during discharging is 0.81%

A. G2V Mode Performance

- Stable EV battery charging with controlled current
- Efficient utilization of solar power
- Reduced grid power draw

B. V2G Mode Performance

- Smooth power injection into the grid
- Stable DC-link voltage regulation
- Effective grid support during load transients

C. Power Quality Analysis

The grid current exhibits low harmonic distortion, and unity power factor operation is achieved, validating the effectiveness of the fuzzy logic controller.

8. Conclusion

This paper presented a solar-powered bidirectional EV charging circuit using fuzzy logic control for grid support applications. The proposed system enables efficient G2V and V2G operation with seamless mode transition and enhanced grid interaction. The fuzzy logic controller ensures robust performance under nonlinear and uncertain operating conditions without requiring an accurate system model. Simulation results confirm improved charging efficiency, stable DC-link voltage, and effective grid support. The proposed approach is well suited for smart grid–integrated EV charging infrastructures and can be extended to hardware implementation and advanced AI-based controllers.

Future Scope

- Hardware-in-the-loop(HIL) validation
- ANFIS or AI-based adaptive control
- Integration with energy storage systems and microgrids
- Real-time grid frequency regulation

9. References

1. N. Sujitha and S. Krithiga, "Grid tied PV-Electric Vehicle Battery Charger using Bidirectional Converter," *Int. J. Renew. Energy Res.*,
2. K. Bhuvaneswara Reddy and V. Ganesh, "Fuzzy logic control for Bidirectional Battery converter for Solar PV applications," *Think India Quart.*,
3. "Fuzzy-Based Efficient Control of DC Microgrid Configuration for PV-Energized EV Charging Station," *Energies*, 2025.
4. "Hardware-in-loop implementation of an adaptive MPPT controlled PV-assisted EV charging system with vehicle-to-grid integration," *Sci. Rep.*, 2025.
5. R. Rana et al., "V2G based bidirectional EV charger topologies and its control techniques: a review," *Discover Appl. Sci.*, 2024.
6. A. Triviño et al., "Decentralized EV charging and discharging scheduling algorithm based on Type-II fuzzy-logic controllers," *Energy Storage*, 2024.
7. Fuzzy Logic-Based Power Management Strategy for Bidirectional Solar-Integrated EV Charging, *ResearchGate*.
8. "Optimized Fuzzy Logic Controller for Responsive Charging of EV," *Sci. Direct*, 2019.
9. Azra Zaineb et al., "Fuzzy Logic Controller Based Charging and Discharging Control for EV Batteries," *Int. J. Electr. Electron. Res.*, 2023.
10. "Vehicle-to-Grid (V2G) Technologies: Impact on the Power System," *Sustainability*, 2022 (overview of V2G impact).
11. J. Lopes, F. Soares, and P. Almeida, "Integration of Electric Vehicles in the Electric Power System," *Proc. IEEE*, 2011.
12. Ehsani et al., "State of the art and trends in electric and hybrid electric vehicles," *Proc. IEEE*, 2021.
13. S. Nagel, E. Jastad, and T. Martinsen, "The grid benefits of vehicle-to-grid in Norway and Denmark," *Energy*, 2024.
14. P. Siddhartha et al., "Integration of renewable energy sources with power

management strategies for effective bidirectional V2G power transfer," *Proc. Comput. Sci.*, 2023.

15. "Research on Charging Machine of Electric Vehicle with V2G Function," *J. Hebei Univ. Water Resour. Electr. Eng.*, 2019 – bidirectional charging fundamentals.