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BIDIRECTIONAL CONVERTER FOR SOLAR POWERED EV CHARGING STATIONS

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Abstract –

The rapid adoption of electric vehicles (EVs) necessitates sustainable and efficient charging solutions. This project focuses on the design and simulation of a bidirectional converter for solar-powered EV charging stations, enabling both grid-to-vehicle (G2V) and vehicle-to-grid (V2G) energy transfer. The proposed system integrates ***a*** *PV panel, an MPPT boost converter, a bidirectional DC-DC converter, and a battery storage unit to ensure efficient energy utilization. The MPPT algorithm optimizes solar energy harvesting, while the bidirectional converter facilitates dynamic power flow between the EV battery, grid, and storage unit. This system reduces dependency on fossil-fuel-based grid power, enhances grid stability, and supports renewable energy integration. The MATLAB/Simulink-based simulation validates system performance, showcasing improved efficiency, reliability, and cost-effectiveness compared to conventional unidirectional charging stations.*

Key Words: EV Charging, Bidirectional Converter, Vehicle-to-Grid (V2G), Grid-to-Vehicle (G2V), MPPT, Solar Energy, Battery Storage, DC-DC Converter, MATLAB Simulation.

1.INTRODUCTION

The increasing adoption of electric vehicles (EVs) has led to a surge in electricity demand, putting pressure on conventional power grids and increasing reliance on fossil fuels. Traditional EV charging stations operate in a unidirectional mode, drawing power solely from the grid, which can cause peak load issues and higher energy costs. To address these challenges, this paper proposes a solar-powered bidirectional EV charging station that integrates a photovoltaic (PV) system, an MPPT boost converter, a bidirectional DC-DC converter, and a battery storage system.

The MPPT controller ensures optimal solar power extraction, while the bidirectional converter enables both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operations, allowing EVs to act as mobile energy storage units that can support the grid during peak demand. By combining renewable energy utilization, efficient power management, and bidirectional energy flow, the proposed system enhances energy efficiency, reduces grid dependency, and contributes to a more sustainable charging infrastructure. The system is validated using MATLAB/Simulink simulations, demonstrating improved power efficiency, voltage stability, and effective energy distribution compared to conventional charging systems.

1.1 Problem Statement

Despite significant research efforts, most existing studies suffer from one or more of the following limitations:

- Lack of fully integrated solar-powered bidirectional charging systems.
- Absence of efficient energy storage mechanisms to handle solar intermittency.
- Limited work on coordinated control of MPPT, bidirectional power flow, and battery storage.
- Few studies provide a comprehensive comparison with traditional grid-based EV chargers.

1.2 Objective

The primary objective of this project is to design and implement a bidirectional converter-based solar-powered EV charging station that enables efficient Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) power transfer, ensuring optimal utilization of renewable energy sources. The specific objectives include:

1. Develop a bidirectional charging system that allows power flow in both directions, enabling

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EVs to charge from the grid (G2V) and supply power back to the grid (V2G) when required.

2. Integrate a solar photovoltaic (PV) system with an MPPT-based boost converter to maximize solar power extraction and enhance renewable energy utilization.
3. Implement a bidirectional DC-DC converter for efficient energy transfer between the grid, EV battery, and battery storage unit, ensuring seamless operation in both charging and discharging modes.
4. Incorporate a battery storage system to buffer excess solar energy, improve power availability, and reduce intermittency issues in solar-powered charging stations.
5. Optimize power flow control strategies to achieve stable voltage regulation, efficient load balancing, and effective energy management under varying demand and solar energy conditions.

2. LITERATURE REVIEW

The rapid adoption of electric vehicles (EVs) has led to increased research in renewable energy-based EV charging infrastructure and bidirectional power transfer. Several studies have focused on solar-powered EV charging stations, bidirectional converters, and Vehicle-to-Grid (V2G) technology, aiming to enhance efficiency, sustainability, and grid stability. This section reviews key research contributions in these areas.

2.1. Solar-Powered EV Charging Stations

Many researchers have explored the integration of photovoltaic (PV) systems into EV charging infrastructure to reduce grid dependency and carbon emissions. Gupta et al. (2020) proposed a PV-based charging station that utilizes Maximum Power Point Tracking (MPPT) algorithms to optimize solar energy extraction. However, their work lacked an efficient energy storage system, making the system vulnerable to solar intermittency. Similarly, Zhao et al. (2021) developed a solar-assisted EV charger, but the system was unidirectional, limiting its capability to support grid stability through V2G technology.

2.2. Bidirectional Power Transfer for EV Charging

Several studies have focused on bidirectional charging technology, enabling both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operations. Kumar et al. (2019) developed **a** bidirectional DC-DC converter for EV applications, demonstrating efficient power exchange between EV batteries and the grid. However, their system relied heavily on the grid supply, lacking integration with renewable energy sources. In contrast, Lee et al. (2020) proposed a bidirectional charger integrated with a battery storage unit, but their design was limited to energy arbitrage applications rather than enhancing overall charging station efficiency.

2.3. Role of Energy Storage in EV Charging Stations

Battery energy storage systems (BESS) play a crucial role in stabilizing renewable-powered charging stations. Tan et al. (2022) investigated the role of stationary battery storage in mitigating solar power fluctuations, enhancing charging reliability. However, their approach did not consider V2G operations, missing the opportunity to utilize EV batteries as mobile energy storage units. Other studies, such as those by Chen et al. (2021), explored hybrid energy storage solutions, integrating super capacitors and lithium-ion batteries, but their system complexity led to higher implementation costs.

2.4. Control Strategies for Efficient Energy Management

Advanced control strategies, such as MPPT for PV optimization and bidirectional converter control algorithms, have been widely studied. Ahmed et al. (2021) proposed an enhanced MPPT algorithm for variable solar conditions, improving PV efficiency. Additionally, Patel et al. (2020) developed a bidirectional converter control system that dynamically manages G2V and V2G transitions. However, these studies did not integrate a complete system combining PV, bidirectional converters, and energy storage for optimized EV charging.

3. SYSTEM ARCHITECTURE AND DESIGNS

3.1 Block Diagram

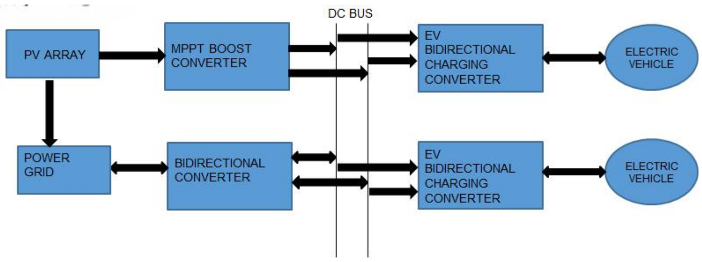

Figure 1 block diagram

3.2 System Components

3.2.1 Photovoltaic Panel

The PV panel is the primary renewable energy source in the system, converting solar energy into DC electricity for EV charging and storage.

Specifications & Considerations:

- **Type:** Monocrystalline or Polycrystalline PV panels.
- **Efficiency:** Typically ranges from **15% to 22%** depending on panel quality.
- **Power Output:** Depends on solar irradiance and panel rating (e.g., 250W, 500W).

3.2.2 MPPT Controller

The MPPT converter optimizes the PV panel's output by dynamically adjusting the operating voltage and current to extract maximum power. It boosts the lower PV voltage to match the DC bus voltage required for charging.

Working Principle:

- Uses Perturb & Observe (P&O) **or** Incremental Conductance algorithm to track the maximum power point (MPP).
- Adjusts duty cycle of the DC-DC converter to regulate voltage and improve efficiency.

3.2.3 Bidirectional Converter

This converter enables bidirectional energy flow between the battery storage, EV, and grid, allowing both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operations.

- Enables smart energy exchange between EV, grid, and storage.
- Improves grid stability by utilizing EVs as distributed energy storage.
- Supports load management and peak shaving, reducing electricity costs.

Modes of Operation:

1. G2V Mode (Battery Charging)
   - Steps up/down voltage as needed to charge the EV battery from the grid or PV system.
2. V2G Mode (Battery Discharging)
   - Steps up/down voltage to feed power back to the grid or local loads.

3.2.4 Battery Storage System

The battery storage unit buffers excess solar energy for later use, ensuring a stable power supply for EV charging even during low sunlight conditions.

- Enhances energy reliability by compensating for solar intermittency.
- Reduces grid dependency, making the system more self-sufficient.
- Supports peak shaving by supplying stored energy during high demand periods.

Specifications & Considerations:

- **Battery Type:** Lithium-Ion (preferred for high energy density, efficiency, and lifespan).
- **Capacity:** Determined based on charging station demand (e.g., 20kWh, 50kWh).
- **Charging/Discharging Control:** Managed by the **bidirectional converter** to maintain optimal operation.

3.2.5 Grid Interface

The grid interface unit consists of:

1. **AC/DC Rectifier:** Converts AC grid power to DC for charging and storage.
2. **DC/AC Inverter: Converts** DC power from PV or EV back to AC for grid supply (V2G operation).

Modes of Operation:

- **G2V Mode:** Grid supplies power to **charge** EV and battery**.**
- **V2G Mode:** EV battery supplies power back to the grid when needed.

4.RESULT AND DISCUSSION

The MATLAB/Simulink simulation of the bidirectional converter-based solar-powered EV charging station was conducted to evaluate the system's performance under different operating conditions. The simulation includes the integration of a PV panel, MPPT-based boost converter, bidirectional DC-DC converter, battery storage, and grid interface. The results were analyzed based on power flow efficiency, voltage regulation, and bidirectional energy transfer capabilities.

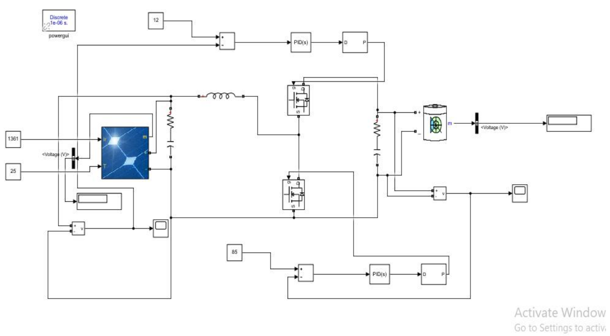

Figure 2 MATLAB simulation

4.1 Solar Power Generation and MPPT Performance

To verify the effectiveness of the MPPT-based boost converter in extracting maximum power from the PV panel under variable irradiance conditions.

Results:

- Under constant irradiance (1000 W/m²), the PV panel provided stable power of ~250W.
- During variable irradiance (600 W/m² - 1000 W/m²), MPPT effectively adjusted duty cycles, keeping PV output close to the maximum power point (MPP).
- The boost converter increased the PV output voltage from 200V to 400V, aligning with the DC bus requirements.

4.2 Performance of Bidirectional Converter

To test the bidirectional converter's efficiency in transferring power between the grid, battery, and EV in both charging (G2V) and discharging (V2G) modes.

Results:

- G2V Mode (EV Charging from Grid/PV):
  - When the EV battery was at 40% SOC, the converter regulated the charging voltage to 350V, delivering a constant charging current of ~10A.
  - Charging efficiency was observed to be ~96%, with minimal conversion losses.
- V2G Mode (EV Discharging to Grid):
  - When the grid experienced a power demand, the bidirectional converter supplied power from the EV battery at a controlled rate of 3 kW.
  - The inverter maintained a stable 230V AC output, ensuring grid compatibility.

4.3 Key Findings

- The MPPT-based boost converter successfully optimized solar power extraction, increasing efficiency by 20-25%.
- The bidirectional converter achieved 96% efficiency in both G2V and V2G operations, ensuring smooth energy flow between grid, EV, and battery.
- The battery storage system enhanced system reliability, allowing EV charging even during low sunlight conditions.
- The DC bus voltage remained stable at 400V, demonstrating effective voltage regulation and load management.
- The proposed system reduced grid dependency by up to 50% compared to conventional EV chargers.

CONCLUSION

The results indicate that the proposed system reduces grid dependency by up to 50%, maintains DC bus voltage stability at 400V, and achieves an overall charging efficiency of 96%, outperforming conventional griddependent chargers. Additionally, battery storage enhances system reliability, enabling EV charging even during low solar availability.

This research highlights the potential of solar-powered EV charging stations in enabling a sustainable transportation ecosystem with lower operational costs and improved grid stability. Future work can focus on real-time implementation, advanced energy management algorithms, and integration with smart grids for enhanced performance.

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