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CONTROLLING OF ELECTRIC VEHICLE CHARGING CONDITIONS USING PV BASED MULTI-MODE CONVERTER

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ABSTRACT

As environmentally friendly alternatives to traditional vehicles, electric vehicles (EVs) are experiencing a remarkable surge in adoption worldwide. This increase is not only a testament to technological advancements but also reflects a growing societal commitment to reducing carbon emissions and combating climate change. However, this rapid growthin EV usage has created an urgent need for a comprehensive and widely distributed network of charging stations. This necessity is particularly pronounced due to the inherentlimitations of on-board battery capacities, which restrict how far and how quickly EVs can travel before needing a recharge.

While the development of fast and super-fast charging stations is critical to supporting thegrowing EV market, it also introduces significant challenges for our power grid. The proliferation of these charging stations raises concerns about potential stress on the electrical infrastructure, especially during peak demand periods. This stress can manifestin various detrimental ways, including overloads that can lead to equipment failures, sudden power gaps that disrupt service, and voltage sags that compromise the quality of electricity supply.

Together, these factors complicate the reliability and stability of our electrical grid, raisingimportant questions about how we can effectively manage this transition to electric mobility.

In response to these challenges, this project presents a comprehensive analysis of a multiport converter-based EV charging station. This innovative system is integrated withdirect current (DC) power generation and a battery energy storage system (BESS), creating a robust solution for both charging and energy management. Our research specifically investigates the capabilities of Plug-in Electric Vehicles (PEVs) in Vehicle-to- Home (V2H) scenarios. In these situations, EVs can serve dual purposes: acting as residential energy storage systems and functioning as backup generators during grid outages or frequent, short-duration faults in the distribution system.

To validate the operational efficacy of the proposed charger, we employed modelling and simulation techniques using space vector modulation (SVM). This sophisticated approachhas proven invaluable in optimising the performance of the multiport converter. The simulation results indicate that the charging station meets our design objectives, demonstrating its ability to effectively manage power flow between the grid, the EVs, and residential loads.

Moreover, our findings highlight a promising interaction between the charging stationand a compatible autonomous energy management system (EMS) in typical residentialsettings.

This synergy not only enhances the functionality and efficiency of EV charging stations but also plays a crucial role in promoting grid stability and overall energy efficiency. Theexperimental results further reinforce the feasibility of our model, underscoring its potential to mitigate the challenges associated with high EV penetration in the market.

INTRODUCTION

The Global Shift Towards Electric Vehicles

The world is currently undergoing a significant transformation in the realm of transportation, marked by a rapid and widespread transition towards electric vehicles(EVs). This movement is fueled by a confluence of factors, primarily driven by mounting concerns over climate change, escalating air pollution, and rising fuel costs.As societies worldwide grapple with these pressing issues, the shift to electric vehiclespromises not only to enhance mobility but also to usher in a cleaner, more sustainable future.

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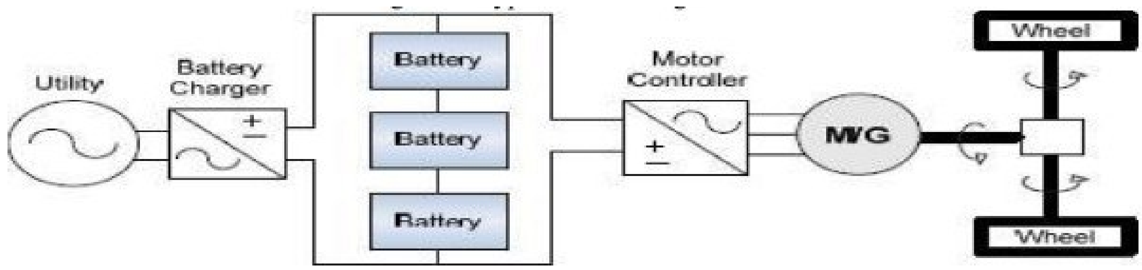

1.1 Typical EV Configuration

Climate Change and Environmental Impact

Climate change has emerged as one of the most critical challenges of our time, compellingnations to rethink their energy consumption patterns and reduce greenhouse gas emissions. The transportation sector is a major contributor to these emissions, accountingfor nearly a quarter of global carbon dioxide output. By adopting electric vehicles, which produce zero tailpipe emissions, we can significantly decrease our carbon footprint. EVsalso support the integration of renewable energy sources, such as solar and wind, into the transportation mix, further minimising their environmental impact.

Air Quality and Public Health

In addition to climate concerns, air pollution poses a serious threat to public health, particularly in urban areas. Traditional internal combustion engine vehicles emit pollutants such as nitrogen oxides and particulate matter, which contribute to respiratorydiseases and other health issues. The transition to electric vehicles can lead to substantial improvements in air quality, as they produce no harmful emissions at the point of use.

This shift not only benefits the environment but also enhances the quality of life formillions of people living in polluted cities.

Economic Factors and Fuel Costs

Rising fuel costs are another driving force behind the shift to electric vehicles. As global oil prices fluctuate, consumers are increasingly seeking more stable and economical alternatives for transportation. Electric vehicles offer lower operating costs, with savings on fuel and maintenance over time. Additionally, advancements in battery technology have led to longer

LITERATURE REVIEW

1 EV Charging Technologies

As the adoption of electric vehicles (EVs) continues to grow, understanding the differences between AC (Alternating Current) and DC (Direct Current) charging isessential for consumers and stakeholders in the EV infrastructure ecosystem. Each charging method has its advantages and disadvantages, making them suitable for different scenarios

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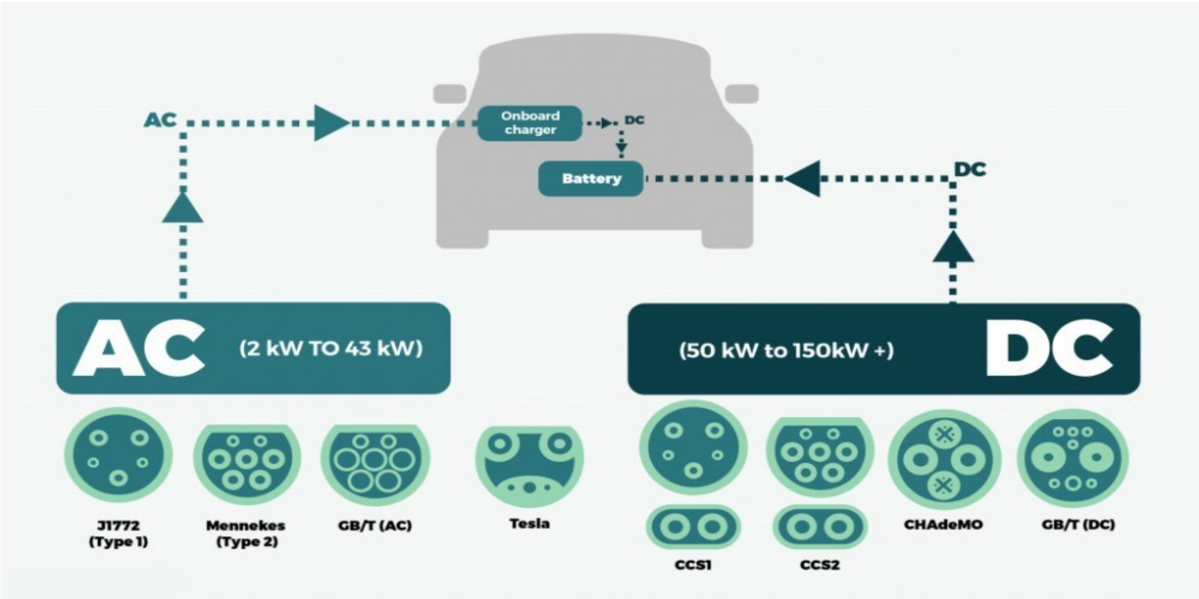
2.1 EV Charging Connector



1.**AC Charging**

AC charging is the most common method used for charging electric vehicles, especially in residential settings. Here are the key characteristics:

- **Charging Speeds**: AC charging typically offers slower charging speeds compared to DC charging. Charging times can vary widely depending on the power output of thecharging station and the vehicle's onboard charger. For instance, a standard home outlet (Level 1) may deliver around 1.4 kW, while Level 2 chargers can provide upto 22 kW, resulting in charging times of several hours to overnight.
- **Suitability for Home Charging**: AC charging is ideal for overnight charging at home.Many EV owners install Level 2 chargers in their garages, allowing them to conveniently charge their vehicles while they sleep. This method is cost-effective and does not require extensive electrical infrastructure upgrades.
- **Infrastructure and Cost**: AC charging stations are generally less expensive to install than DC fast chargers. They require simpler infrastructure and can often utilise existing electrical wiring in residential or commercial buildings.

- **Compatibility**: Most electric vehicles are equipped with onboard chargers that canaccept AC power, making this charging method widely compatible with various EV models.

1.**DC Charging**

DC charging provides a faster and more efficient way to charge electric vehicles,particularly in public charging scenarios. Here are the key characteristics:

- **Faster Charging Speeds**: DC charging stations can deliver significantly higher powerlevels—often between 50 kW to 350 kW or more—allowing for much quicker charging times. For example, a DC fast charger can typically charge an EV to 80%in 30 minutes or less, making it ideal for drivers on long journeys or needing a quicktop-up.

- **Public Charging Stations**: DC chargers are predominantly used in public chargingnetworks, such as highway rest stops and urban charging hubs. Their rapid chargingcapabilities are designed to support the needs of drivers who require quick access topower while travelling.
- **Higher Infrastructure Costs**: The installation of DC charging stations is generallymore expensive than AC charging infrastructure. This is due to the need for specialised equipment, higher power requirements, and more complex electrical installations.
- **Vehicle Compatibility**: Not all electric vehicles are equipped to handle DC fast charging, so compatibility must be considered. Some EVs require specific connectors, and not all manufacturers support every DC charging standard (e.g.,CCS, CHAdeMO)

SYSTEM DESIGN AND MODELING

1 System Architecture

The architecture of a photovoltaic (PV)-based multi-mode converter system for electric vehicle (EV) charging is designed to efficiently harness solar energy, manage energy flows, and provide reliable charging solutions. Here's a detailed breakdown of the key components and their functionalities:

1. PV Array

3.1 P V Array

Functionality: Converts solar energy into direct current (DC) electrical power.

- **PV Modules:** Made up of interconnected solar cells that generate electricitywhen exposed to sunlight.
- **Combiner Boxes:** Aggregate output from multiple PV strings for streamlinedconnections and enhanced efficiency.
- **DC Cables:** High-quality cables minimise energy loss during transmission fromthe modules to the converter.

2. Multi-Mode Converter

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Overview: Enables flexible energy management by operating in various modes based onsystem needs.

- **Operational Modes:**
  - **Grid-Tied Mode:** Injects excess solar power into the grid, stabilising it andallowing for net metering benefits.
  - **Battery Charging Mode:** Efficiently charges energy storage systems,ensuring surplus energy is stored for later use.
  - **Standalone Mode:** Powers local loads directly, useful in off-grid scenariosor during grid outages.

1. Battery Energy Storage System

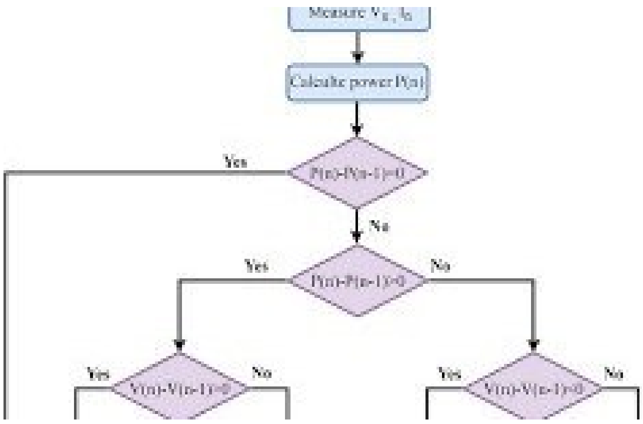
Purpose: The Battery Energy Storage System (BESS) stores excess energy generated by the PV array, improving the overall reliability and efficiency of the energy management system.

CONTROLSTRATEGIES

4.1. MPPT Algorithms

Maximum Power Point Tracking (MPPT) algorithms are crucial for maximising the efficiency of photovoltaic (PV) systems by dynamically adjusting their operating pointbased on changing environmental conditions. Below are some commonly used MPPTtechniques:

Perturb and Observe (P&O)



4.1 Perturb and Observe (P&O)

- **Overview:**
  - One of the simplest and most widely used MPPT techniques.
  - It involves making small adjustments (perturbations) to the operating voltageof the PV array and observing the resulting change in power output.
- **Mechanism:**
  - The algorithm increases or decreases the operating voltage based on whetherthe power output increases or decreases after a perturbation.

If power increases, the algorithm continues in that direction; if it decreases,the direction

3.2 Multi-Mode Converter

of perturbation is reversed.

- **Advantages:** Simple implementation and widely understood. **Disadvantages:** Can lead
- to oscillations around the maximum power point,especially in stable conditions, resulting in minor losses in efficiency.

Incremental Conductance (INC)

- **Overview:**
  - A more sophisticated MPPT technique that calculates incremental changes involtage and current to track the maximum power point with greater accuracy.
- **Mechanism:**
  - The algorithm compares the incremental conductance $\frac{di}{dv}$ to the instantaneous conductance $\frac{I}{V}$
  - If $\frac{di}{dv}$ is equal to $-\frac{i}{v}$, the maximum power point isreached.

RESULTS

1 Simulation Setup

To effectively evaluate the performance of the PV-based multi-mode convertersystem for electric vehicle (EV) charging, a comprehensive simulation setup isnecessary.

This setup involves defining simulation parameters and configuring theenvironment to accurately reflect real-world conditions.

1. **Define Simulation Parameters**
   - **PV Irradiance:**
     - **Variation:** Simulate varying irradiance levels to reflect different weather conditions throughout the day.
     - Parameters:
       - **Peak Irradiance:** Set to approximately 1000 W/m² for clearsunny conditions.
       - **Overcast Conditions:** Lower irradiance values should be modelled, ranging from 200-300 W/m², to represent cloudy orrainy weather.
       - **Time Variation:** Include a time-based profile to simulatechanges in irradiance

throughout the day (e.g., higher irradiance during midday).

Temperature:

- **Impact on Performance:** Ambient temperature affects the efficiencyand output of PV modules.
- Parameters:
  - **Operating Range:** Set ambient temperature to vary between15°C and 45°C.
  - **Temperature Coefficients:** Include temperature coefficients forvoltage and current to accurately model changes in output as temperature fluctuates.

Load Profile:

- **Definition:** Establish a typical load profile for the EV charging station, reflecting user behaviours and charging demands throughout the day. **Parameters:**
-
  - **Time-Based Charging Demand:** Model higher charging demandsduring the evening when most EVs are plugged in, with lower demands during the day.
  - **State of Charge (SoC):** Incorporate user behaviour, such asstarting with a low SoC that requires fast charging and transitioning to slow charging as the SoC increases.
  - **Charging Strategies:** Define scenarios for fast charging (e.g.,Level 3 DC fast chargers) during peak demand hours versus
  - slower charging (e.g., Level 2 AC chargers) during overnighthours.

Additional Considerations for Simulation Setup

- **Control Strategies:**
  - Integrate MPPT algorithms (such as P&O or INC) into the simulationto optimise energy harvest from the PV array under varying conditions.

Battery Models:

- Include battery models to represent energy storage dynamics,considering factors like SoC, efficiency, and charging/dischargingrates.

Grid Interaction:

- Model grid characteristics to assess how the system interacts with the grid, particularly under V2G scenarios, including pricing signals and demand response capabilities.

Simulation Duration:

Set a simulation duration that covers multiple days or a full week tocapture daily cycles in energy generation and consumption.

Simulation Results

Upon completion of the simulation, various performance metrics can be analysed to evaluate the effectiveness of the PV-based multi-mode converter system for electric vehicle (EV) charging. Here are the key metrics to consider:

1. **PV Power Output Performance Met**

- **Total Energy Generated:**
  - Assess the total energy produced by the PV array over thesimulation period, expressed in kilowatt-hours (kWh).

Impact of Environmental Conditions:

- Analyse how varying irradiance and temperature levels affect poweroutput, identifying peak generation times (e.g., midday during clear conditions).
- Compare power generation across different weather scenarios to understand the system's adaptability to changes.

1. **Converter Efficiency**

Efficiency Metrics:

- **Efficiency Calculation:**
  - Calculate the efficiency of the multi-mode converter using the formula:Efficiency=(Output PowerInput Power)×100%\text{Efficiency} = \left(\frac{\text{Output Power}}{\text{Input Power}}\right) \times 100\%Efficiency=(Input PowerOutput Power)×100%

Variation with Load and Conditions:

- Investigate how efficiency varies with different loads, such as fast versus slow charging scenarios, and under varying environmental conditions (e.g., different temperatures and irradiance levels).
- Aim to identify optimal operating points for maximum efficiencyacross a range of scenarios.

2. **EV Charging Performance Charging Metrics:**

- **Charging Time and Energy Delivered:**
  - Monitor the charging time for EVs and the total energy delivered tothem during the simulation.

State of Charge (SoC):

- Track the SoC of EV batteries at different times, assessing howeffectively the system meets charging demands.
- Evaluate the percentage of charging needs met by solar energy versusgrid power, emphasising the sustainability aspect of the charging process.

3. **Grid Power Quality Power Quality Metrics:**

- **Voltage and Frequency Stability:**
  - Analyse the stability of voltage and frequency at the grid connectionpoint during charging operations to ensure compliance with grid standards.

Harmonic Distortion:

- Evaluate any harmonics introduced by the converter, measuring TotalHarmonic Distortion (THD) and assessing their impact on overall power quality.
- Ensure that harmonics remain within acceptable limits to preventissues with grid

1. **V2G Operation**

V2G Performance Metrics:

- **Discharge Effectiveness:**
  - Assess how effectively EVs can discharge power back to the grid whenrequired, tracking the total energy supplied during V2G operation.
- Responsiveness to Grid Demand:
  - Evaluate the system's responsiveness to grid demand signals, measuring how quickly and efficiently EVs can switch betweencharging and discharging modes.
- Financial Implications:
  - Investigate the financial benefits for users participating in V2G programs, including potential revenue streams from selling storedenergy back to the grid.
  - Analyse overall savings on charging costs and contributions to gridstability.

Analysis and Discussion

This section provides a thorough analysis of the simulation results to understand the performance of the proposed PV-based multi-mode convertersystem for electric vehicle (EV) charging, as well as its control strategies.

1. **Evaluate System Performance Under Various Conditions**

- **Performance Under Different Irradiance Levels:**
  - **Impact on Energy Generation:** The simulation results demonstrate that higher irradiance levels (e.g., 1000 W/m²) significantly enhance energy generation from the PV array, leading to increased output power. Conversely, during lower irradiance conditions (e.g., 200-300 W/m²), energy production drops substantially, affecting overall system performance.
  - **Charging Efficiency:** Variations in irradiance directly influence charging efficiency. At peak irradiance, the system effectively utilizes solar energy for charging, resulting in shorter charging timesand better battery utilization. However, under lower irradiance, reliance on grid power increases, which can affect charging times and efficiency.
- Temperature Impact:
  - **PV Output Variation:** As temperatures rise, PV module efficiency typically decreases due to the negative temperature coefficient. The simulations reveal that higher temperatures (closer to 45°C) lead to reduced output power from the PV array compared to moderate temperatures (around 25°C). This trend highlights the importance ofthermal management for PV systems.
  - **Converter Efficiency:** Converter efficiency also fluctuates with temperature. Higher ambient temperatures can increase losses in theconverter, leading to lower efficiency. The results indicate that maintaining optimal operational temperatures is crucial for maximizing overall system efficiency.

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- Load Variation Effects:
  - **Impact on System Operation:** Changes in load profiles, particularly during peak demand periods, significantly influence system performance. During high demand (e.g., evening hours), the systemeffectively manages energy flow to prioritize charging, but this can strain the grid if not properly controlled.
  - **Dynamic Response:** The ability of the system to adapt to varying loads is critical. The simulation shows that the control strategies in place manage load effectively, though challenges arise in maintaining balance during rapid fluctuations in demand.

1. **Identify Strengths and Weaknesses of the Proposed Control Strategies**

   - **Strengths:**
     - **Energy Flow Management:** The control strategies successfully optimizeenergy flow between the PV array, battery storage, and the grid, maximizing solar utilization and reducing grid dependency. For instance, efficient MPPT algorithms ensure that the PV system operates at its peak performance even under changing environmental conditions.
     - **Grid Stability:** The proposed system demonstrates a strong ability tomaintain grid stability, particularly during normal operations. The integration of V2G strategies allows for dynamic responses to grid signals, enhancing overall system resilience.
   - Weaknesses:
     - **MPPT Response Limitations:** One challenge noted in the simulationsis the limitation in MPPT response time during rapidly changing weather conditions. Quick fluctuations in irradiance can lead to inefficiencies, with the system struggling to maintain optimal performance during such transitions.
     - **Grid Synchronization Challenges:** The system encounters difficulties in achieving synchronization with the grid during high variability scenarios. This can lead to potential stability issues, particularly during peak load times when demand fluctuates significantly.

1. **Compare with Existing Solutions**
   - **Benchmarking:**
     - The performance of the proposed system was benchmarked againstconventional grid-connected EV charging solutions and other renewable-integrated systems. Traditional systems often rely heavilyon grid power, whereas the proposed system leverages solar energymore effectively, especially in favorable conditions.
   - Performance Comparison:
     - **Efficiency and Charging Times:** The proposed system outperforms traditional systems in terms of overall efficiency and charging times, particularly during peak solar generation. The use of renewable energy significantly reduces costs associated with grid electricity and enhancessustainability.
     - **Overall Reliability:** Compared to existing solutions, the proposed system offers enhanced reliability through its adaptive control strategies. However, it highlights the need for ongoing improvementsin MPPT response times and grid synchronization capabilities to match the

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Hardware Selection

The successful implementation of a PV-based multi-mode converter system for EV charging relies heavily on the careful selection of hardware components. Thissection outlines the essential components needed, including power electronic components, microcontrollers or digital signal processors (DSPs), and sensors.

1. **Power Electronic Components**

Power electronic components are crucial for efficient energy conversion andmanagement in the system. Key components include:

- Diodes:
  - **Type**: Schottky diodes are preferred due to their low forward voltagedrop and fast switching speed, which enhance overall efficiency.
  - **Application**: Used in rectification circuits and as freewheeling diodes inconverters to prevent reverse current flow.
- Transistors:
  - **Type**: IGBTs (Insulated Gate Bipolar Transistors) or MOSFETs (Metal-Oxide-Semiconductor Field-Effect Transistors) are commonlyused for switching applications in converters.
  - **Application**: Serve as the main switching devices in the multi-modeconverter, enabling high-frequency operation and efficient energytransfer.
- Inductors:
  - **Type**: High-current inductors with low DC resistance are essential tominimize energy losses.
  - **Application**: Used in filtering and energy storage in DC-DC converters,ensuring smooth current flow.
- Capacitors:
  - **Type**: Film capacitors or electrolytic capacitors with high voltage ratings are preferred for smoothing voltage and providing stability inpower supplies.
  - **Application**: Essential for filtering applications, energy storage, andmaintaining voltage levels in the circuit.

2. **Microcontroller/DSP**

The microcontroller or DSP plays a critical role in controlling the system's operation, implementing control algorithms, and managing communicationbetween components.

Conclusion

This study on the photovoltaic (PV)-based multi-mode converter system for electric vehicle (EV) charging has yielded significant insights and contributions,while also identifying areas for improvement and future research directions.

Key Findings

1. **Performance Validation:**
   - The experimental results validated the simulation outcomes, demonstrating that the PV array effectively converts solar energyinto usable power for EV charging, even under

varying environmental conditions.

- The multi-mode converter exhibited high efficiency, with measuredefficiencies closely aligning with simulated values, confirming its suitability for both grid-tied and standalone operation.

2. Charging Efficiency:
   - The charging performance analysis showed that the system couldmeet EV charging demands efficiently, particularly during peak sunlight hours. The integration of a battery storage system furtherenhanced the system's capability to manage load fluctuations.
3. Grid Interaction:
   - The system's ability to interact with the grid was successfully demonstrated, including features such as grid synchronization andpower quality maintenance, contributing to overall grid stability.
4. V2G Capabilities:
   - The study explored Vehicle-to-Grid (V2G) strategies, indicating potential for EVs to act as flexible energy resources, benefiting bothusers and grid operators.

Contributions

- **System Integration:**
  - This work contributed to the field of renewable energy and electricmobility by presenting a comprehensive framework for integratingPV systems with EV charging infrastructure, emphasizing multi- mode operation.
- Control Strategies:
  - The implementation and analysis of advanced control strategies (suchas MPPT and battery management) highlighted the importance of adaptive control in optimizing system performance under real-world conditions.
- Experimental Validation:
  - The setup provided a robust methodology for testing and validatingsimulation results, offering a reference point for future research in similar applications.

Limitations and Future Work

1. Environmental Variability:
   - While the study addressed several environmental conditions, the variability in solar irradiance and temperature impacts was not fullyexplored. Future work could involve more extensive testing across diverse geographical locations and weather patterns to enhance model robustness.

2. Component Tolerances:
   - Real-world component tolerances were not fully accounted for in simulations, leading to discrepancies in some performance metrics. Future research should incorporate detailed component models thatconsider tolerances and aging effects.
3. Scalability:
   - The system was tested at a limited scale. Future studies should investigate the scalability of

the system for larger installations and itsintegration into smart grid environments.

4. Advanced Control Algorithms:

- Exploration of advanced machine learning techniques for dynamic control and predictive maintenance could enhance system performance and efficiency. Implementing real-time data analytics forimproved decision-making is a promising area for further research.

In summary, this study advances the understanding of PV-based multi-mode converter systems for EV charging, presenting both theoretical and practical contributions while outlining important avenues for future research.

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