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BIDIRECTIONAL BATTERY ELECTRIC VEHICLES AS DISTRIBUTED ENERGY STORAGE UNDER GRID EXPORT LIMITATION

Summary

As solar PV becomes more common in buildings and district-scale energy systems, new technical challenges appear alongside its benefits, particularly in cases where electricity export to the grid is restricted. Under these conditions, local control strategies and flexible storage options are needed to use more of the generated renewable electricity on site and to avoid unnecessary curtailment. This study explores an energy management system (EMS) based concept in which bidirectional battery electric vehicles are used as mobile storage assets within residential and office energy networks supplied by PV. Unlike fixed battery systems, Battery Electric vehicle (BEV) can offer flexibility not only over time but also across locations, since energy can be charged at one site and discharged at another. The analysis therefore considers the role of bidirectional charging in limiting grid export, increasing self-consumption of solar electricity, reducing peak demand, and supporting energy exchange between home and workplace. The findings are expected to highlight the strong potential of bidirectional BEVs as an effective storage solution for future sustainable districts when integrated through intelligent EMS control. This approach also supports a closer coupling between mobility and local energy infrastructure, improving overall system flexibility and resilience.

Keywords: Bidirectional BEV, energy management system, grid export limitation, distributed energy storage, sustainable energy infrastructure, electrification, district energy, solar PV

Field of application for the findings: Sustainable energy infrastructure, building and district electrification, distributed renewable energy systems, smart charging and storage integration, bidirectional electric vehicle, export-limited grids, renewable self-consumption optimization, and sustainable district energy planning.

Addressed audience: Researchers, energy system planners, district energy developers, grid operators, building energy managers, e-mobility and EMS specialists

1. Introduction

The electrification of buildings, transport, and distributed renewable generation is reshaping future energy infrastructure. Although photovoltaic systems are increasingly installed in homes, offices, and commercial buildings, their efficient use is often limited by mismatches between generation and local demand, as well as restrictions on feeding surplus electricity into the grid. As a result, part of the available solar energy is often curtailed or insufficiently utilized.

At the same time, battery electric vehicles offer more than just clean mobility. With bidirectional charging, they can also serve as flexible and mobile energy storage units. In contrast to stationary batteries, BEVs can absorb energy at one location and deliver it later at another, creating new possibilities for shifting renewable electricity between places such as offices and homes.

This study examines the potential of bidirectional BEVs within an EMS-controlled local energy system operating under grid export limits. The aim is to assess how such vehicles can improve solar self-consumption, reduce curtailment, smooth grid exchange, and support more efficient interaction between residential and office energy systems. This approach is especially relevant for future sustainable districts, where energy, mobility, and control can be managed in an integrated way. It also highlights how vehicle-based storage can contribute to a more flexible and resilient local energy network.

2. System concept and implementation

The proposed system consists of PV generation, building electrical loads, bidirectional BEV charging infrastructure, optional stationary battery storage, and a grid connection operating under export limitation as shown in Fig. 1. The system is coordinated by an energy management system that continuously monitors PV production, load demand, state of charge of available storage, vehicle availability, travel schedule constraints, and grid exchange conditions.

The EMS prioritizes direct use of locally generated PV electricity. When on-site demand is lower than PV production and export is restricted, the surplus energy is directed to flexible storage resources. In this context, the BEV becomes a key storage asset. During office parking hours, the vehicle can be charged using surplus PV electricity from the office building. After traveling to the residential location, the stored energy can be discharged to support household demand, reduce evening grid import, or provide backup flexibility. The same principle can operate in reverse if the residential site has surplus renewable generation or if different tariff and load conditions make reverse transfer beneficial.

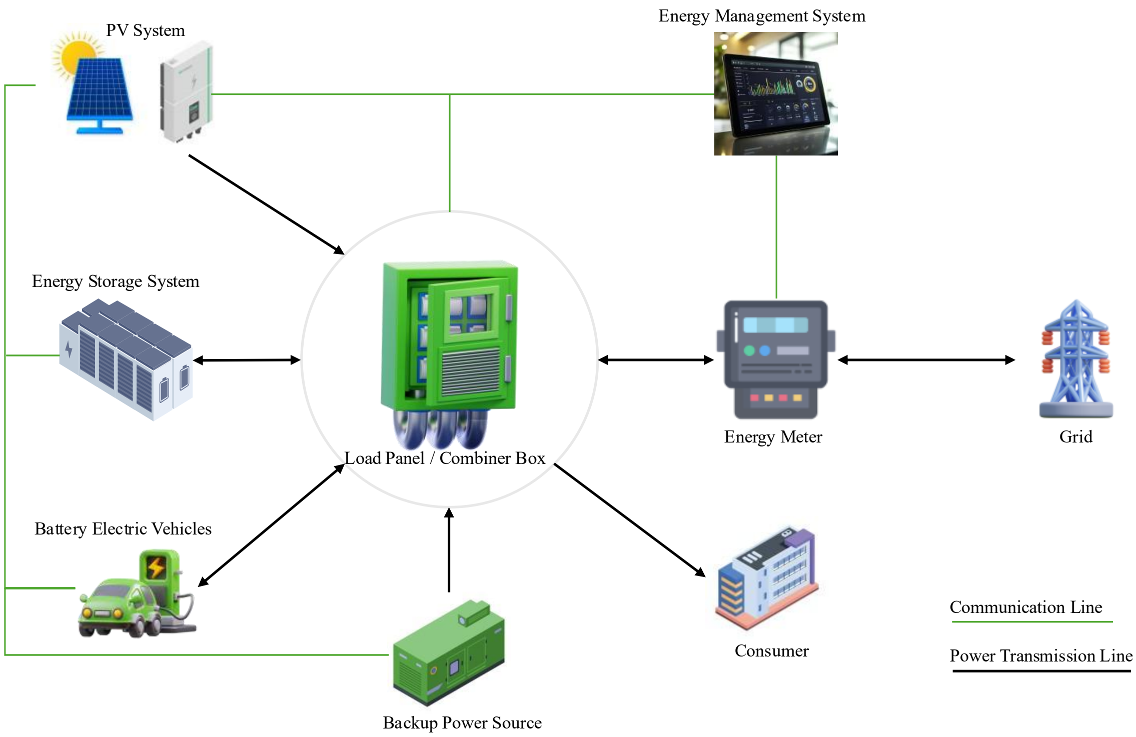

Fig. 1: Conceptual EMS-controlled energy infrastructure with PV generation, BEV, battery storage, office and residential loads, and constrained grid interaction.

The system concept therefore extends beyond conventional self-consumption optimization. It combines local PV generation, distributed electrification, and vehicle-based energy transfer across locations. In this way, the BEV is treated as a mobile distributed battery integrated into the wider sustainable energy infrastructure. Stationary battery storage can additionally be considered for comparison, but the main focus of the concept is the storage value and operational flexibility delivered by the bidirectional vehicle.

3. Technical methodology

The study is based on modelling and simulation of representative residential and office scenarios connected through daily BEV mobility. The energy model includes time-resolved PV generation, building load demand, export limitation constraints, vehicle arrival and departure times, charging and discharging power limits, state of charge evolution, and EMS control logic. The simulation framework is designed to evaluate the interaction between renewable electricity generation, distributed storage, mobility-linked energy transfer, and controlled grid exchange.

Different operating scenarios are assessed in order to quantify the added value of bidirectional BEV integration. These include direct PV self-consumption without storage, PV with stationary battery storage, unmanaged EV charging, and EMS-controlled bidirectional BEV operation. The comparative analysis focuses on technical key performance indicators such as renewable self-consumption ratio, avoided PV curtailment, reduction in grid export peaks, reduction in grid import peaks, storage utilization, and effective use of vehicle battery capacity for infrastructure support.

Special attention is given to the distinction between temporal and spatial flexibility. Stationary batteries can shift energy in time, but they remain fixed to one location. In contrast, bidirectional BEVs can both shift energy in time and relocate it physically between buildings through normal travel behavior. This enables new operational possibilities for interconnected home-office systems and for future districts with mixed-use energy demand structures.

4. Results and discussion

The results suggest that grid export limits can significantly reduce the useful share of PV generation when no flexible storage is available. In this case, uncontrolled EV charging is often insufficient and may even worsen demand peaks. In contrast, EMS-based bidirectional charging can capture excess solar electricity, reduce curtailment, and use that energy later where it provides greater benefit.

A key strength of the bidirectional BEV is its dual role as both transport and storage. This allows energy to be moved between office and home, offering an advantage over fixed batteries when generation and demand occur at different locations. The findings also underline the importance of the EMS, since effective coordination of charging, discharging, vehicle availability, and export limits is essential for unlocking this flexibility and improving local and district-level energy performance.

5. Conclusion

This study proposes an EMS-based energy infrastructure concept in which bidirectional BEVs function as mobile and distributed storage under grid export constraints. The approach addresses rising PV integration in electrified buildings and districts by using BEVs to capture surplus solar electricity, shift it over time, and transfer it between residential and office locations. The results are expected to show that this strategy can improve self-consumption, reduce curtailment, and support more balanced grid interaction. Overall, bidirectional BEVs appear to be a promising storage option for future sustainable and efficient districts.

6. References

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