PV-Powered Charging Stations

Sizing, Optimization and Control

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Executive Summary

Electric mobility is accelerating worldwide, increasing the demand for cleaner and more sustainable charging solutions. Among the most promising options are photovoltaic (PV)-powered charging stations (PVCS), which integrate solar energy production with electric vehicle (EV) charging infrastructure. These systems are becoming increasingly common in both urban and rural settings, reflecting a global shift toward renewable energy integration and greater energy autonomy.

However, the effective deployment of PVCS involves more than simply installing solar panels and chargers. Key challenges include the dimensioning of PV generation and storage systems to meet local energy demands, the management of energy flows between the PV source, the grid, and potential battery storage, and the control of EV charging to ensure system stability, operational efficiency, and user satisfaction. Without proper coordination, PVCS may face issues such as overloading, underutilization, or intermittent service availability.

Building on the initial IEA Task 17 Subtask 2 report—which examined the feasibility and fundamental requirements of PVCS – and a second report that addressed technical solutions and societal impacts, this third report advances the work further. It explores the deployment of PVCS within microgrid-based architectures, the integration of smart energy management and charging systems, and the incorporation of emerging services such as Vehicle-to-Grid (V2G) and battery swapping. It also considers the specific requirements and challenges related to charging electric buses with solar energy.
Effectively addressing these technical and operational aspects is essential to fully realize the potential of PV-powered charging, ensuring not only environmental sustainability, but also system reliability and economic viability.

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A. Sizing for EV Workplace Charging Station

This goal is to maximize on-site solar energy for charging electric vehicles via a dedicated control system. A modular sizing methodology was developed that separates the sizing problem into four relationships, allowing business model, charging strategy, and demand profile to vary independently, giving stakeholders flexibility to adapt the approach to different real-world scenarios. Results show that aligning charging with PV generation can greatly reduce infrastructure needs and costs. Workplace parking lots are especially suitable, as EV demand often matches predictable daytime solar production.

B. PVCS: Sizing and Energy Cost Optimization

The optimal sizing and operation of PVCS in microgrid contexts involve complex trade-offs among technical, economic, and environmental objectives. A multi-objective framework based on MILP was developed to minimize both the levelized cost of energy (LCOE) and life cycle emissions (LCE) over the station’s economic lifespan. Results show that while high solar irradiation improves both LCOE and LCE, site-specific conditions (e.g., climate, energy demand, grid availability) necessitate customized designs. The choice of PV and battery technologies plays a crucial role in achieving balanced outcomes.

C. PVCS: Integration of Vehicle-to-Grid (V2G) Services

Since EVs are parked for extended periods, V2G services offer mutual benefits for grid operators and EV owners. A MILP-based optimization algorithm was designed to schedule EV battery charging and discharging, aiming to minimize energy costs while maximizing solar utilization. Simulations demonstrated that dynamic scheduling strategies outperform static ones, yielding economic benefits without compromising driver requirements.

D. PVCS for Electric Buses

The deployment of electric buses in public transport highlights both their environmental advantages and deployment challenges. A case study in Compiègne, France, evaluated the impacts of various charging strategies – depot-only, terminal, and opportunity charging – on grid performance and service reliability. The integration of PV generation was assessed for its role in reducing emissions and grid stress. Results show significant trade-offs among strategies, affecting battery sizing, operational flexibility, and infrastructure demands. Although opportunity charging reduces battery size and energy consumption, it also imposes stress on the grid and requires costly infrastructure. Seasonal variability also limits solar potential in winter, reinforcing the need for energy storage.

Key Findings

A. Sizing for EV Workplace Charging Station:

- Using the Mean Power strategy instead of Plug and Charge halved (≈50 % reduction) the size of the required PV plant.
- Using the Solar Smart Charging strategy reduced the needed PV peak power to about one-third compared to the basic Plug and Charge scenario.
- The modular approach means that once the four relationships are computed for a “representative” site, other similar sites can be sized in hours instead of weeks—this is valuable for a CPO managing many workplace charging stations.

B. PVCS Sizing and Energy Management:

- Off-grid setups require larger components to handle low-sun periods;
- Higher battery capacity is associated with lower LCE; more PV panels improve LCOE;
- Economically optimal systems require higher initial investments, while environmentally optimal setups lead to increased long-term replacement costs;
- Greater grid interaction improves both economic and environmental outcomes;
- In the French case study, 54% of energy was locally produced, with the rest supplied primarily by the nuclear-dominated public grid.

C. V2G Integration:

- Small-scale V2G (e.g., residential) has limited impact but contributes to flexibility;
- Large-scale implementations (e.g., 100 EVs in a campus setting) provide better returns and support grid services more effectively.

D. Electric Buses and PVCS:

- Electric Buses reduce tailpipe emissions and contribute to urban air quality improvement;
- Depot-only charging: Simple, but leads to night-time grid peaks and larger battery requirements;
- Terminal + Depot charging: Reduces peak demand but needs more infrastructure;
- Opportunity charging: Cuts battery size by 83% and energy consumption by 9.4%, but stresses the grid due to high-power demands;
- PV integration lowers CO_2 emissions and eases peak demand, especially during high-use periods;
- Solar contribution is limited in winter, requiring battery storage for consistency.

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