Implementation Schemes for Electrified Bus Fleets at Intra-Urban Depots with Optimized Energy Procurements in Virtual Power Plant Operations

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Introduction and Motivation

For the purpose of utilizing electrified bus fleets and providing an active energy management, a profound understanding of fleet characteristics is presented. To lower the complexity for market participation and provision of power system services novel Virtual Power Plant (VPP) services (see Fig. 1) are proposed.

Solution Approach and Objectives

- Implementation schemes for charging infrastructure and processes at an intra-urban depot are introduced
- Integrated charging strategies with energy procurements in joint market operation are presented
- Enhanced Virtual Power Plant optimization models are developed and flexibilities for providing nodal redispatch measures are put into evidence

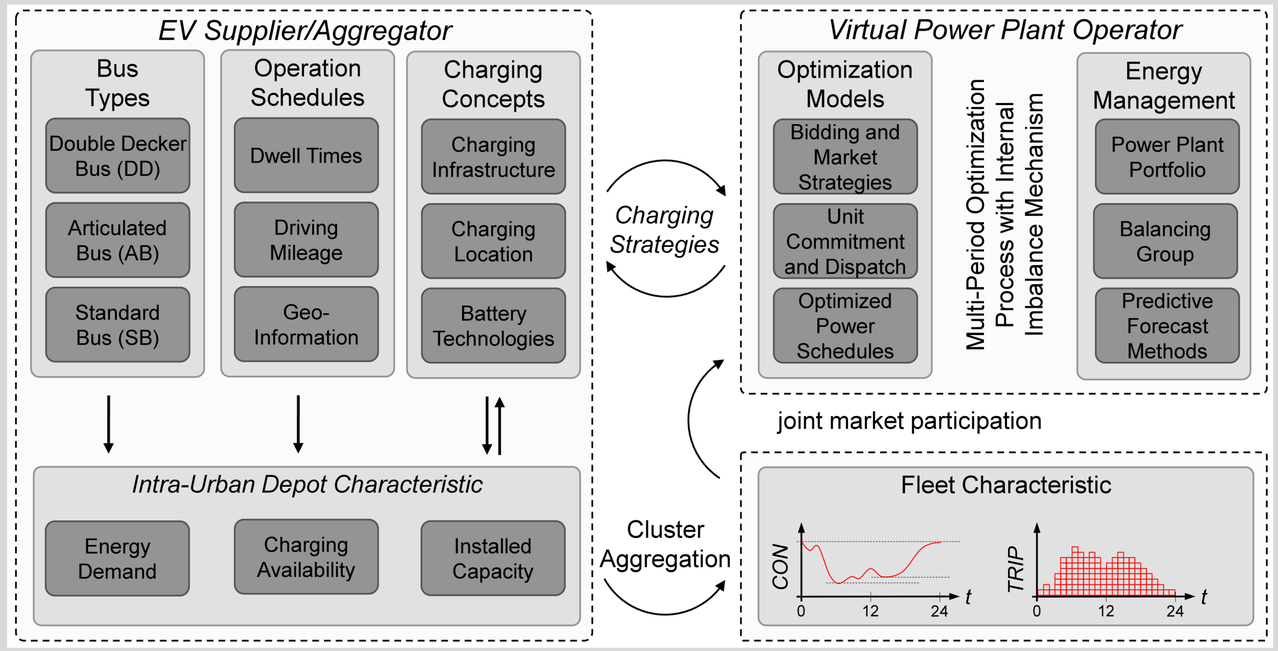

Fig. 1: Implementation schemes for the operation of electrified bus fleets.

Bus Type Specific Models

Field-recorded fueling and consumption data are analyzed by using the efficiency method to specify the electrical energy equivalents for bus type specific models:

Tab. 1: Energy demands of developed electrified bus models.

unit model*)	energy capacity (kWh)	weekly mileage of driving (km)	specific energy demand (kWh/km)	daily energy demand (kWh)
SB	175	1,045/1,147/1,469	1.30/1.80/2.30	245-345
AB	225	1,135/1,231/1,566	1.80/2.50/3.10	368-508
DD	250	1,118/1,231/1,500	1.90/2.60/3.30	385-517

*) standard bus (SB), articular bus (AB), double decker bus (DD)

Strategies for 1st-base depot charging and 2nd-base opportunity charging are analyzed (see Fig. 2) by separating the energy demands as follows:

$$\boldsymbol{E}_{\mathrm{d}}^{fleet} = \boldsymbol{E}_{\mathrm{d}}^{fleet,1\mathrm{st}} + \boldsymbol{E}_{\mathrm{d}}^{fleet,2\mathrm{nd}}$$
$$= \boldsymbol{CON}^{1\mathrm{st}} \cdot P_{\mathrm{r}}^{tariff} \cdot \eta^{mod} \cdot \Delta t^{mod,1\mathrm{st}} + \boldsymbol{CON}^{2\mathrm{nd}} \cdot P_{\mathrm{r}}^{tariff} \cdot \eta^{mod} \cdot \Delta t^{mod,2\mathrm{nd}}$$

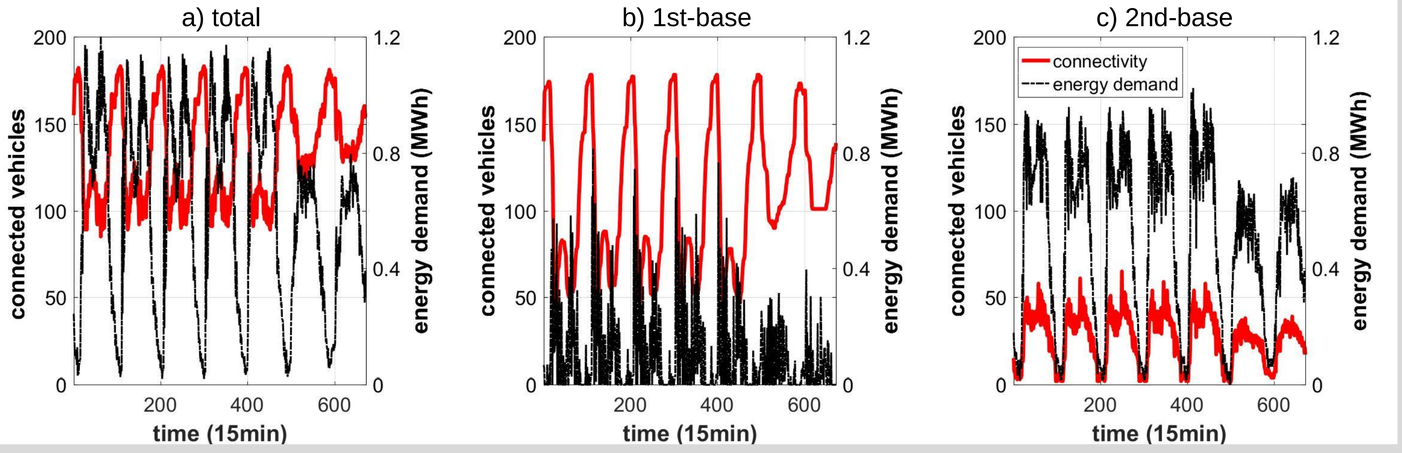

Fig. 2: Connectivity and energy demand profiles of electrified bus fleet.

Depot Charging Possibilities

By analyzing the operation processes at an intra-urban depot, three charging possibilities are identified (see Fig. 3) where in general sufficient time and space are available: (a) parking on shunting area, (b) additionally during service and (c) parking on waiting area after entry. Subsequently, different charging scenarios with non- and partly-controlled charging are investigated.

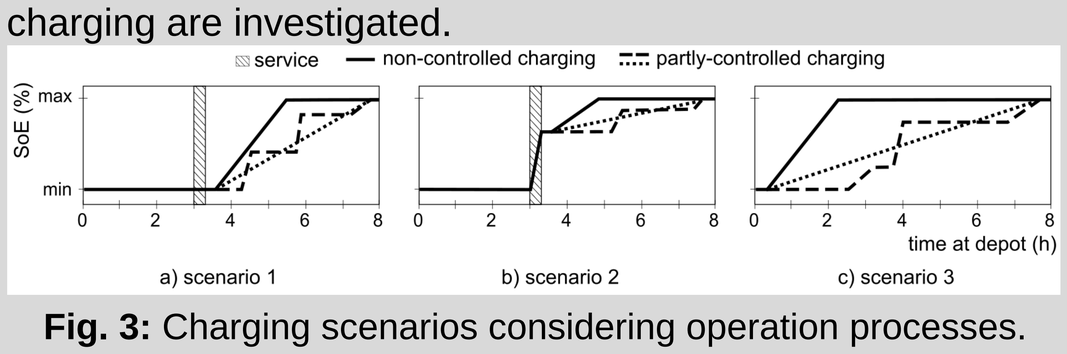

Fig. 3: Charging scenarios considering operation processes.

Depot Charging Profiles

For evaluation purposes a total number of 193 buses is considered. Next, the physical layout of the charging infrastructure at the intra-urban depot is designed and corresponding charging profiles (see Fig. 4) determined.

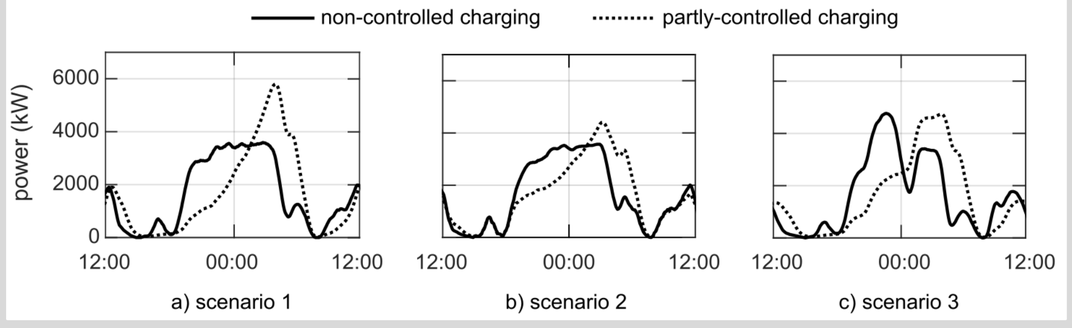

Fig. 4: Charging profiles of electrified bus fleet on weekdays.

Computational Study and Dispatch Results

Charging power is optimally adjusted for each time step in the day-ahead and intraday market operation by utilizing the developed Virtual Power Plant services. This allows:

- provision of optimized energy procurements
- usage in power plant portfolio operations

Extreme condition tests are performed (see Fig. 5) to identify nodal redispatch measures and provision of possible system services.

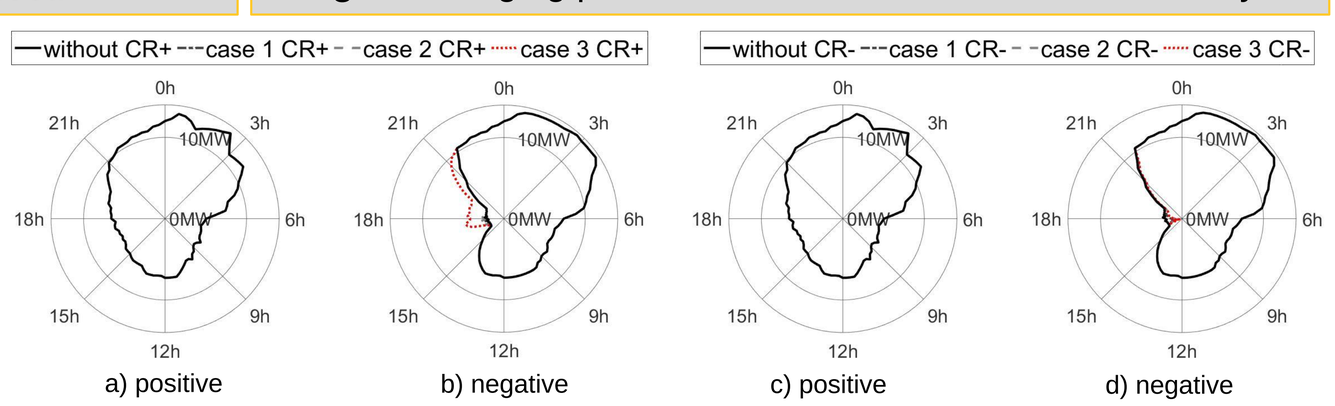

Fig. 5: Available (a), (c) positive and (b), (d) negative reserve capacity response on positive CR+ and negative CR- reserve power requests.

Conclusion

Comprehensive simulation frameworks show integrated solutions for market entities involved in the charging process of electrified bus fleets. This covers co-operative solutions for EVS/A, VPP and system operators.

The operation processes at an intra-urban bus depot are analyzed and implementation schemes for different charging strategies substantiated in numerical simulations. It is shown that the energy demand for the operation of the electrified bus fleet can be efficiently supplied by joint market operation thanks to novel Virtual Power Plant services proposed here. Moreover, the developed charging strategies allow reducing the peak loads while providing additional control reserve capacity for system services.

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