Literature review: Modelling of Electric Vehicle Charging Behaviour

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Introduction

Most of the vehicles today are concentrated at Electric Vehicle (EVs), which introduces to new and dynamic loads to local electrical networks. The precise modelling of EV charging behaviour is crucial to advanced evaluation on their impact on power systems and for developing simulation tools with its help charging behaviour under different constraints.[1] This Theis focus on modelling of single electrical vehicle charging session, with focused on relation between charger power limits, battery state of charge (SoC), and the resulting power over time.

Rather than modelling the grid-level effects or multiple vehicle interruptions, the scope of this work is intentionally limited to single EV connected to a controlled, monitored charger. This simplification provides a transparent and detailed formulation of the charging process while maintaining computational efficiency. [1] The literature reviewed in this chapter provides the

theoretical calculation and foundation for selecting a suitable mathematical model that balances physical realism with implementation simplicity.

Charging Power Characteristics of Electric Vehicles

Several studies shows that the EV charging behaviour are a constrained process in which the actual charging power have different variables determined by both external and external limitations [1]. The external limitations are accounted for chargers and the power that charger is willing to output while the internal limitations are the batteries capabilities to take the power in at given state of charge (SoC).

The commonly used expression for the instantaneous charging power as minimum of these 2 constraints:

$$P_{actual}(t) = \min (P_{charger}(t), P_{battery}(SoC(t)))$$

This formulation is widely used in the EV industries due to its physical interpretability and clarity [1],[2]. Now it allows the charger power to be represented as either constant or time varying constraint, meantime the battery acceptance power captures the dependency on the internal battery state.

The internal variable: the battery acceptance power typically follows a characteristic constant-current-constant-voltage (CC-CV) charging profile. At lower charger states; SoC level, the battery can accept higher power, corresponding to constant-current (CC) region. As battery SoC level moves higher the charging power reduces to prevent overvoltage, overcharging and accelerated degradation [3], [4].

Battery State of Charge Modelling

The battery state of charge (SoC) is key variable in electric vehicle charging models, as it directly influences both the charging power and the total energy stored in the battery. In many simulation-oriented studies, SoC is treated as a normalise representation of the battery's stored energy relative to its nominal capacity [2],[4].

Among all research on EV charging simulations, the commonly acquired approach models the evolution of SoC using an energy balance equation in discrete time. In this formulation, the SoC is updated based on the actual power delivered to the battery over a fraction of given time. The general state of this update equation is given below:

$$SoC(t + \Delta t) = SoC(t) + \frac{\eta \cdot P_{actual(t)} \cdot \Delta t}{E_{battery}}$$

Where η represents the charging efficiency, $P_{actual}(t)$ is instantaneous charging power, Δt is the simulation time step (in milliseconds) and $E_{battery}$ denotes the nominal battery capacity of the battery. This formulation here is used in most of the academic literature and practical engineering applications due to its form of simplicity and transparency [1], [3].

Review studies on battery modelling emphasize that such energy-based SoC formulations are well suited for system-level simulations, particularly when the objective is to analyse charging power profiles and energy accumulation rather than detailed electrochemical behaviour *[4]*. While more complex models exist that capture internal battery dynamics with higher fidelity, their increased computational complexity and parameter requirements often make them impractical for high-level charging simulations.

Charger Power Constraints and Control

The charger plays a critical role in shaping the charging profile of an electric vehicle by enforcing power limitations that may be fixed or time dependent. In controlled charging scenarios, the charger specifies the maximum allowable power that acts as upper limit of the charging boundary during the charging process. *[1],[3]*.

In the literature, chargers are frequently modelled as power-limited sources rather than ideal energy suppliers. Under this abstraction, the charger does not guarantee that the maximum power will be drawn by the vehicle; instead, the actual charging power depends on both the charger constraint and the battery's instantaneous acceptance capability *[1], [2]*.

This modelling approaches allows the charger power constraint to be either constant unchangeable value or time varying signal, accepting the simulation of different charging strategies, such as load limiting or demand and response. By combining the charger power constraints with the battery power acceptance model, it becomes a potential way to compute the instantaneous charging power at each time step, providing an intermediate charging response to changes in charging conditions and environment.

Model Assumptions and Simplification

To be intact with the calculations, align with intended scope and maintain traceability of the thesis, several formulations and assumptions are taken from the existing literature. While battery degradation effects are neglected. Charging efficiency is also considered as constant throughout the charging process *[2],[4]*. Temperature dependent effects are either ignored or represented through fixed parameters rather than represented dynamically.

Furthermore, the model focuses exclusively on a single electric vehicle and does not account for interactions with other vehicles, loads, or grid components. Such simplifications are common in component-level and early-stage modelling studies, where the primary objective is to capture the fundamental characteristics of individual charging behaviour *[1], [3]*.

Previous studies demonstrate that, when appropriately parameterized, simplified charging models can reproduce realistic charging power curves observed in experimental data. Therefore, it opens the possibility of relying on simulation studies being focused on clarity, flexibility, simplicity and computational efficiency over complex electrochemical details.

Resulting Model Concept

Based on the reviewed literature, this thesis adopts a discrete-time electric vehicle charging model in which the battery state of charge is treated as the primary state variable. The instantaneous charging power is calculated as the minimum of the charger-offered power and the battery acceptance power, which is modelled as a function of the current SoC [1], [2].

The battery state is updated at each simulation step using an energy balance equation, and the model produces time series outputs for both charging power and state of charge. This modelling approach provides a clear and literature-supported framework for simulating single-vehicle charging behaviour under varying power constraints.

The described model serves as the basis for the subsequent implementation phase, in which the charging behaviour will be simulated in Python and calibrated using the available charging dataset.

Refrences

[1] (Design and Prototype Modelling of a CC/CV Electric Vehicle Battery Charging Circuit | IEEE Conference Publication | IEEE Xplore (2026). Available at: https://ieeexplore.ieee.org/abstract/document/8821071 (Accessed: 12 January 2026).)

[2] Reisz, Petra. reposiTUm: Development of an electric vehicle and battery pack simulator (2026). Available at: https://repositum.tuwien.at/handle/20.500.12708/199627 (Accessed: 14 January 2026).

[3] Emulating Real-World EV Charging Profiles with a Real-Time Simulation Environment (2026). Available at: https://www.mdpi.com/2075-1702/13/9/791 (Accessed: 14 January 2026).

[4] Plett, G. L. (2004). Extended Kalman filtering for battery management systems of LiPB-based HEV battery packs. *Journal of Power Sources*, *134*(2), 277–292. https://doi.org/10.1016/j.jpowsour.2004.02.033(Accessed: January 14)