Optimal V2G Scheduling for Individual EVs under Departure Uncertainty and User Behavior in Microgrid Systems via Transfer Learning–Enhanced Reinforcement Learning

Myungsuk Chae, Dongjun Won

Department of Electrical and Computer Engineering, Inha University

Introduction

- With the accelerating adoption of electric vehicles, their aggregated charging demand is emerging as a critical factor affecting grid stability and energy balance
- Unlike conventional static loads, EV charging patterns are highly uncertain, driven by user-specific schedules and behavioral variability.
- This uncertainty complicates the prediction of departure times and travel distances, resulting in inefficiencies in Vehicle-to-Grid operations and potential degradation of battery health.

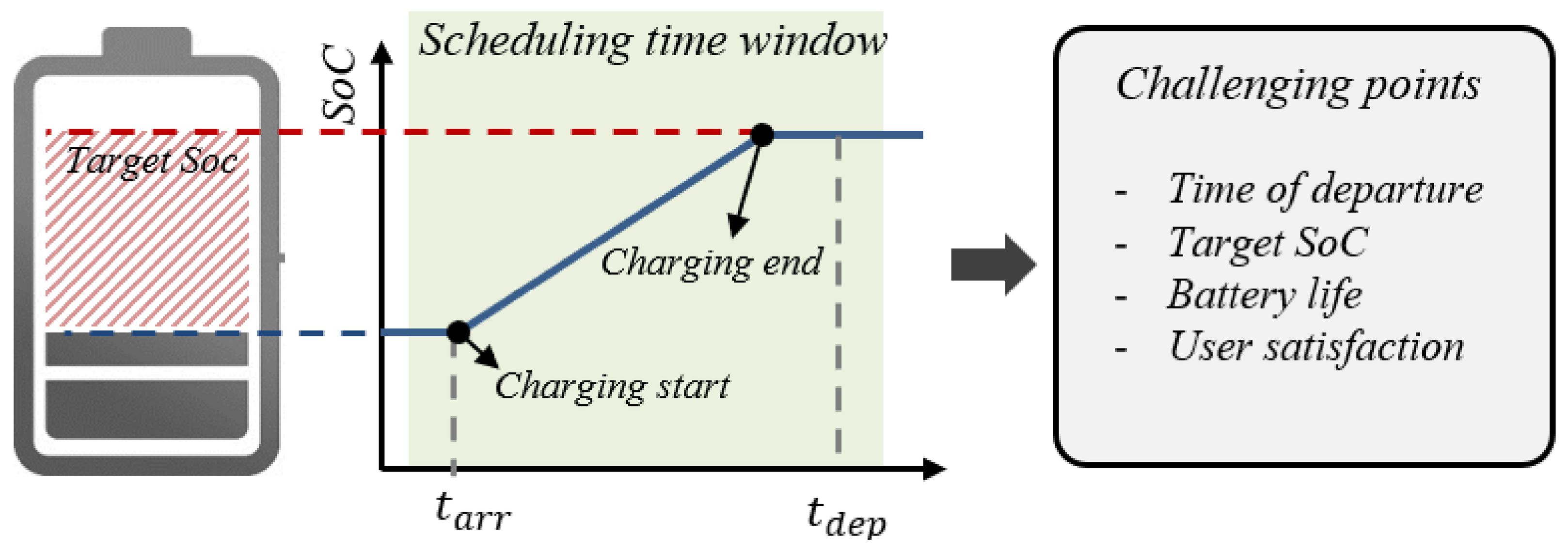

Fig. 1. Uncertain factors of EVs and challenging points.

- To address this, we develop a 2-Stage Reinforcement Learning framework that predicts individual departure patterns and optimizes V2G charge-discharge operations by considering user satisfaction, cost, and battery degradation
- Validated with real-world data, the proposed model mitigates departure uncertainty, enhances user comfort, and improves long-term battery performance for resilient V2G integration.

Methodology

1. 2-Satge EV Uncertainty Model

- The proposed 2-Stage EV Uncertainty Model employs an LSTM-based prediction to estimate each vehicle's expected driving distance and required State of Charge.
- By incorporating user satisfaction into these predictions, individualized driving behavior and energy needs are reflected in the scheduling process.
- An Actor-Critic reinforcement learning model then optimizes the reward function to maximize profit while ensuring efficient and user-centric V2G operation.
- Using LSTM and considering user satisfaction, the values for $\widetilde{d_{n,T}}$ (expected driving distance) and $SoC_{n,T}^{req_n}$ (required State of Charge) are calculated. The model optimizes the reward function to maximize profit while ensuring efficient and user-satisfactory V2G operations.

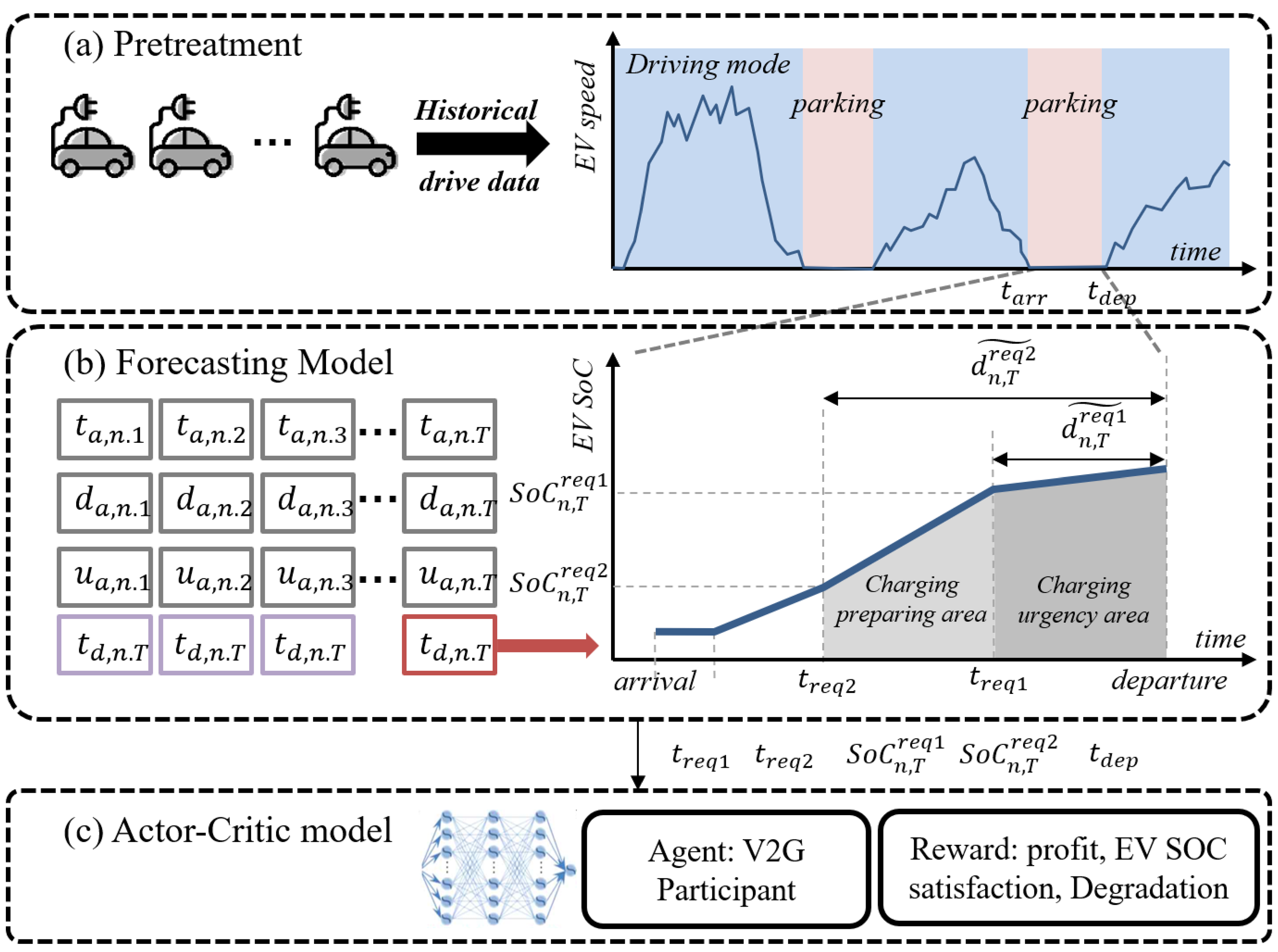

Fig. 2. 2-Stage EV uncertainty model framework

2. System Model Formulation

- The battery lifecycle cost model is based on the LFP battery, which is widely used in EVs. This lifecycle evaluation model incorporates four key stress factors: temperature, average SoC, DoD, and time.

$$f_d = [S_\delta(\delta) + S_t(t_c)] \cdot S_\sigma(\sigma) \cdot S_T(T_c) \quad (1)$$

$$L = 1 - \alpha_{sei} e^{-\beta_{sei} \cdot f_d} - (1-\alpha_{sei}) e^{-f_d} \quad (2)$$

- The Anxiety Model of EV Users determines its values in Stage 1, based on expected driving distance and required State of Charge.

$$f_{anxiety,t} = \frac{\vartheta_{n,t} - t_{n,p}}{\vartheta_{n,t}} \cdot f_{d-stress}(soc) \quad (3)$$

- The Bellman function can be simplified to a Q-learning problem with discrete action variables. The linear combination of EVs battery aging cost, user anxiety, driving behavior and grid power balancing requirement are formulated as the reward function

$$A = \{u, x\} = \{-1, P_d\} \cup \{0, P_0\} \cup \{1, P_c\} \quad (4)$$

$$r = \alpha \cdot [-L_t - w_a \cdot f_{anxiety} - CB_t - \beta \cdot (PB_t^2 - P_{EV} * n)] \quad (5)$$

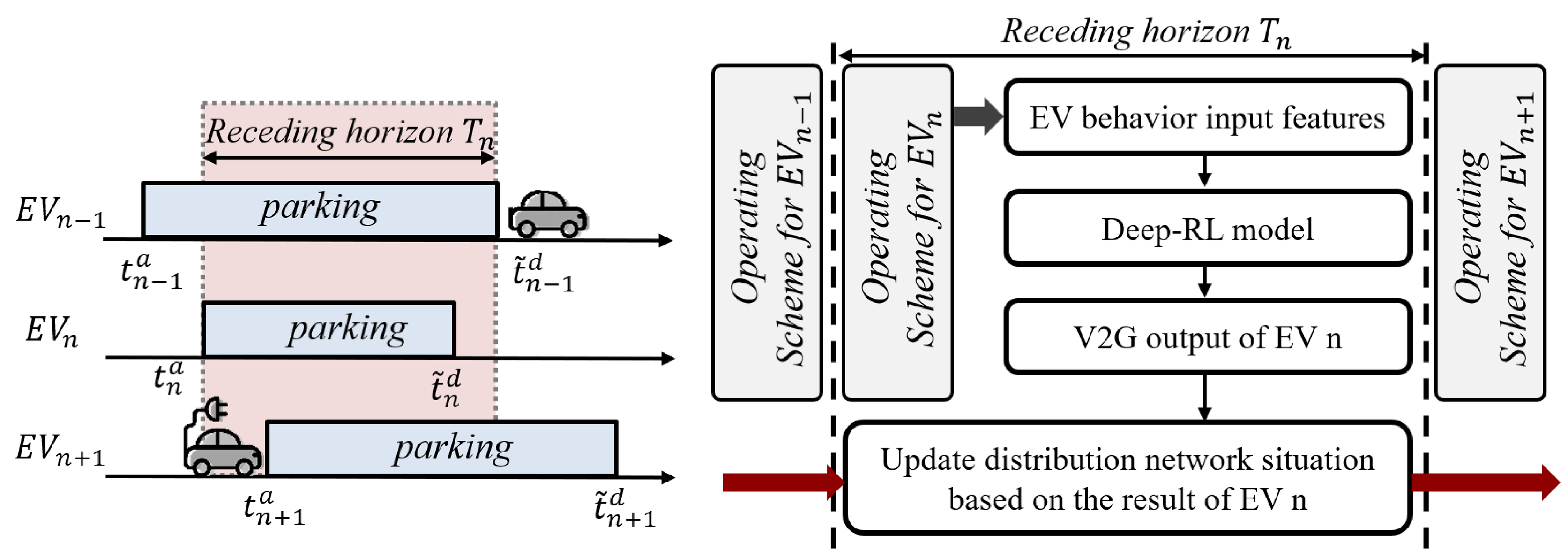

Fig. 3. Schematic of the algorithm execution.

3. Simulation Results

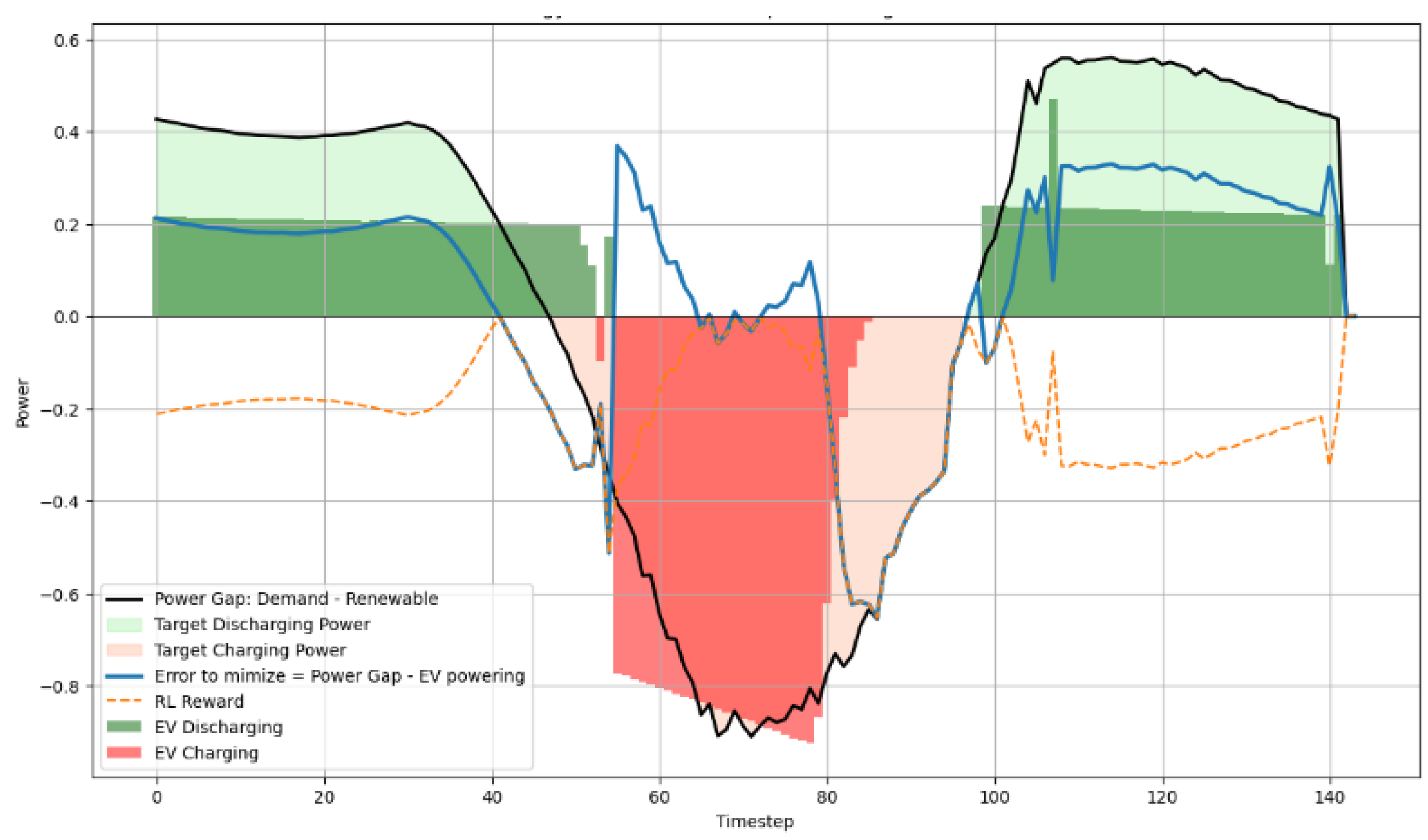

Fig. 4. Result of Case Study.

- The proposed model effectively optimizes individual EV V2G operations within a microgrid, enhancing user satisfaction, profitability, and battery longevity while maintaining grid stability.

Conclusion

- The microgrid applied in this study incorporates renewable energy sources, including PV and wind generation, while the loads consist of residential demands and EVs.
- Analyzing the charging and discharging outcomes reveals that all vehicles reduced excessive charging and discharging fluctuations to preserve battery lifecycle costs.
- Furthermore, the target SoC levels for charging were finely adjusted based on individual driving patterns, demonstrating the system's adaptability and optimization in meeting both user and grid requirements.

IPSL Inha Univ. Power System Lab