EVs as Non-Wires Alternatives for Microgrids: A Virtual Power Line Framework

Yeongsang Lee, Dongjun Won

Department of Electrical and Computer Engineering, Inha University

Introduction

- The rapid growth of electric vehicles (EVs) is deepening the link between transportation and power networks, creating new challenges in grid stability and infrastructure cost.
- EVs equipped with vehicle-to-grid (V2G) capability can act as Non-Wires Alternatives (NWAs), forming a Virtual Power Line (VPL) that delivers power flexibility without physical expansion.
- This study develops a co-optimization framework integrating EV scheduling and routing to enhance renewable hosting capacity and reduce traffic congestion, enabling sustainable energy-mobility interaction.

Modeling & Simulation

1. VPL Framework and Algorithm

- The Virtual Power Line (VPL) algorithm jointly optimizes EV scheduling and routing under grid and traffic constraints.
- In the time-shifting mode, commuting EVs act as distributed storage for peak shaving using time-of-use tariffs.
- In the location-shifting mode, traveling EVs are rerouted to charging stations near PV farms to absorb excess renewable generation.
- Together, these modes enable EVs to function as flexible grid assets that enhance stability and renewable utilization.

$$min\left(\rho_s P_{peak} + \sum_t \rho_e(t)[P_{Load}(t) - P_{EV}(t)]\right) \quad (1)$$

$$min \sum_t \rho_e(t) \sum_k P_k^{grid}(t) \quad (2)$$

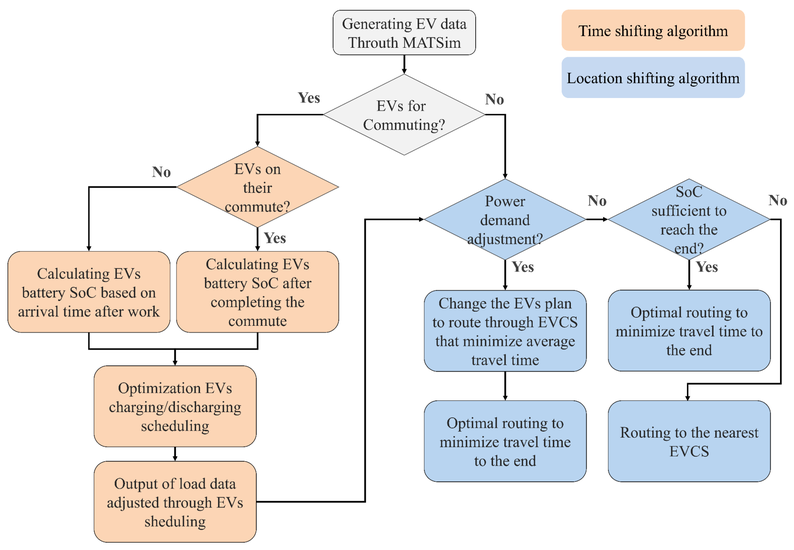

Fig. 1. Flowchart of the VPL algorithm process

2. Simulation Setup

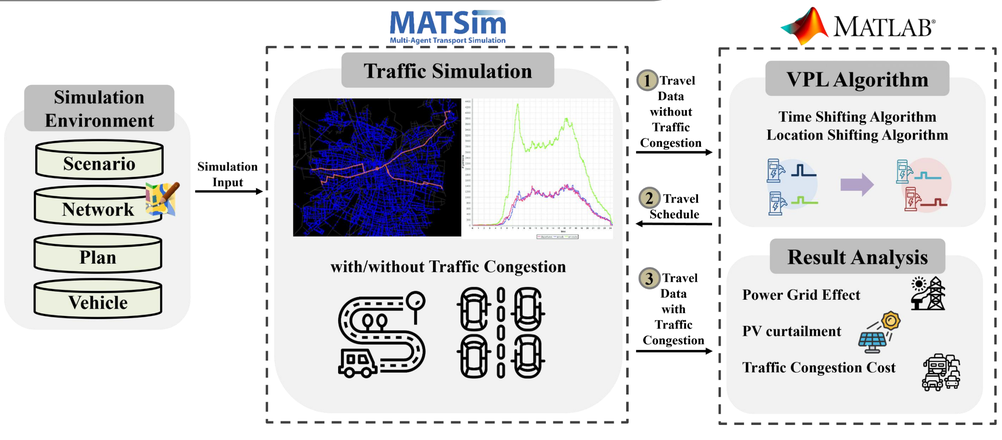

Fig. 2. Integrated power-transportation simulation model

- The proposed framework was validated using Jeju Island, which has Korea's highest EV and renewable penetration.
- The simulation integrates MATSim for traffic flow and MATLAB for power-system optimization, forming a coupled transport-grid digital twin.
- A total of 2,000 EVs and 10 charging stations were modeled—1,500 for time-shifting and 500 for location-shifting—based on scaled Jeju traffic and load profiles.

3. Simulation Results

- Results – Power System Impact
- The time-shifting algorithm smooths daily load variation, improving the grid's load factor from 79 % to 88 % and shifting about 34 MWh from peak to off-peak hours.
- The location-shifting scheme decreases PV curtailment by 11 %, line losses by 6 %, and raises renewable hosting capacity by 15 %, maintaining a 98.6 % voltage-compliance rate.
- These results confirm that coordinated EV operation can stabilize the grid and defer costly infrastructure upgrades.

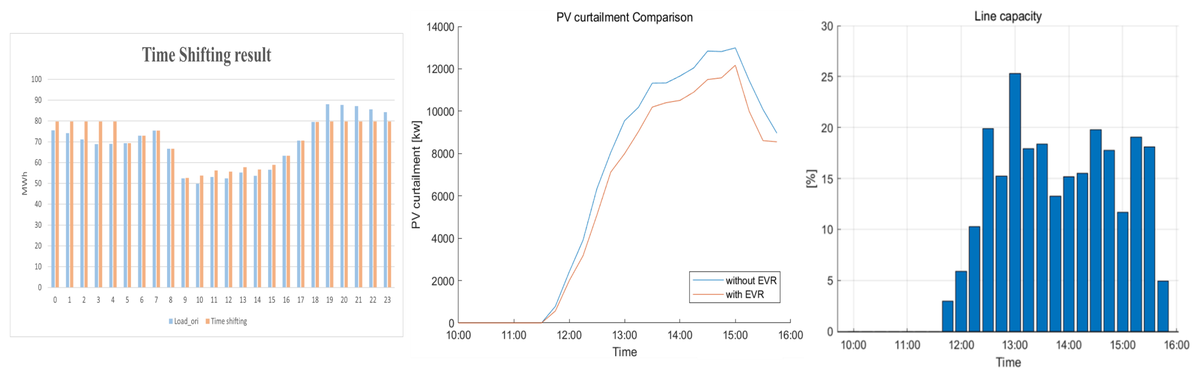

Fig. 3. Impact of EV-Based Virtual Power Line on Grid Operation

- Results – Power System Impact
- Under the location-shifting scenario, 191 EVs were rerouted. Average travel distance rose slightly (+6 %), yet mean travel time fell 7.7 %, and average speed increased 15 %.
- The overall congestion cost dropped 43.7 % (₩1.28 M → ₩0.72 M), showing that EV routing improves both traffic flow and energy efficiency.
- Coordinated control therefore benefits mobility as well as grid economy.

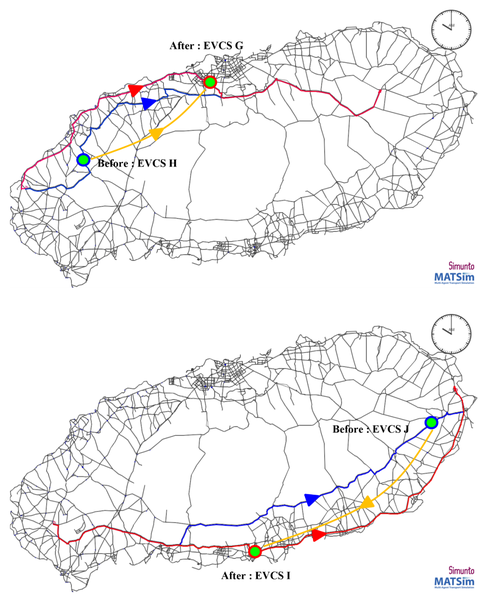

Fig. 4. EV routing adjustment and travel efficiency improvement

TABLE I
CHANGE OF TRAFFIC INDICATORS AFTER EVR

Indicators	Before routing	After routing	Variation
Avr. Time (mins)	60.00	55.58	-7.67%
Avr. Distance (km)	58.15	61.88	+6.42%
Avr. Speed (km/h)	57.55	66.33	+15.26%
VOC (₩)	107k	111.7k	+4.16%
OC (₩)	1176k	611.1k	-48.03%
Congestion Cost(₩)	1283.1k	722.8k	-43.67%

Conclusion

- This study presents a Virtual Power Line (VPL) concept that treats EV fleets as distributed non-wires alternatives. By combining time-shifting and location-shifting operations, EVs contribute to peak shaving, renewable integration, and congestion relief.
- Simulation results demonstrate that VPL improves grid load factor by 9 %, increases renewable hosting capacity by 14.8 %, and reduces traffic congestion cost by 43.7 %.
- The results validate the feasibility of using EVs as mobile energy assets that strengthen both grid stability and transport efficiency without physical expansion.
- Future work will explore market-based incentive mechanisms and probabilistic forecasting to manage uncertainties from EV user behavior and renewable generation variability.

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