Optimizing Time-of-Use Rates for Electric Vehicles in Decarbonizing Industrialized Nations: Design Strategies and Effectiveness Assessment

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Abstract

This study analyzes the cost-effectiveness of a Time-of-Use (TOU) tariff-based electric vehicle (EV) charging strategy as a means of enhancing power system flexibility during renewable energy integration in industrialized countries. In particular, it compares the economic benefits and grid integration contributions of EV-TOU—a demand-side flexibility resource—with those of a representative flexibility resource, the Energy Storage System (ESS).

To conduct this analysis, we developed an integrated EV charging behavior–power system model that combines: (1) an EV user charging behavior model, (2) a TOU pricing optimization model, and (3) a power system expansion and operation planning model. Preferences for EV charging attributes were identified through a Discrete Choice Experiment (DCE) involving 1,033 residents of South Korea. Based on this, we forecasted changes in EV charging demand before and after implementing TOU tariffs.

An optimal TOU pricing structure was designed to flatten net load profiles, taking into account seasonal and weekday/weekend characteristics. The impacts of this strategy on power system operations were then compared with those of ESS deployment scenarios.

The analysis showed that TOU tariff implementation effectively shifted EV charging demand to daylight hours, reducing renewable energy curtailment and net load variability. In particular, free charging during weekend daytime hours significantly narrowed the demand gap between weekdays and weekends. From an economic perspective, the TOU-based EV charging strategy achieved similar curtailment mitigation effects as ESS deployment but at a significantly lower total cost. This study highlights the potential of TOU-based EV charging as a cost-effective policy tool for integrating growing shares of renewable energy into the grid in industrialized countries.