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Operational Resilience Value of EV Flexibility under Historically Grounded Climate Stress

摘要

电动汽车在增加电力需求的同时，也为电力系统提供了可调度的负荷灵活性。本文评估了在短时历史极端气候压力事件下，电动汽车有序充电与车网互动（V2G）对未来电力系统运行韧性的影响。研究基于中国 2060 年省级小时尺度 PyPSA-China-TIMES 电力系统模型，在年度基准情景确定发电装机、固定储能功率与能量容量、以及省间输电容量后，将三个持续 48–72 小时的历史气候压力事件施加到固定资产系统上，并比较无序充电、有序充电和有序充电叠加 V2G 的运行结果。结果表明，在事件天气与无序充电条件下，三个事件窗口内全国未满足电力需求达到 5.50–19.49 TWh。有序充电可降低 1.08–3.40 TWh 的未满足电力需求，V2G 进一步提供 0.24–0.58 TWh 的额外削减。综合有序充电与 V2G 后，事件窗口内未满足电力需求相对于无序充电降低 20.4%–23.9%。结果说明，在短时极端气候导致集中供需紧张时，电动汽车充电灵活性能够提供可量化的运行韧性价值，其中有序充电是主要贡献来源，V2G 提供较小但稳定的增量贡献。

关键词

电动汽车；有序充电；车网互动；极端气候；电力系统韧性；

Abstract

Electric vehicles (EVs) are increasingly relevant to power-system resilience because they add electricity demand while also creating flexible load. This study estimates the operating value of EV charging flexibility in a 2060 Chinese power system exposed to short historical climate-stress events. Three 48–72 hour climate-stress events are imposed on a provincial PyPSA-China-TIMES power-system model after installed generation capacity, stationary-storage power and energy capacity, and inter-provincial transfer capacity have been fixed from an annual baseline. Under event weather with uncontrolled charging, national unserved electricity demand reaches 5.50–19.49 TWh within the historical event windows. Smart charging reduces these shortfalls by 1.08–3.40 TWh, and V2G provides a further 0.24–0.58 TWh reduction. The combined smart-charging-plus-V2G response lowers event-window unserved electricity demand by 20.4–23.9%, indicating that EV flexibility can provide measurable operating resilience when short-duration climate stress creates concentrated scarcity.

Keywords

electric vehicles; smart charging; vehicle-to-grid; climate extremes; power-system resilience;

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