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A multi-stage techno-economic model for harnessing flexibility from IoT-enabled appliances and smart charging systems: Developing a competitive local flexibility market using Stackelberg game theory

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Abstract-

The increasing integration of renewable energy sources with power systems has led to greater uncertainties, heightening the need for more flexible services. Demand-side resources can provide significant flexibility cost-effectively, making it crucial to design new business models to harness their flexible capacities. Hence, this paper introduces a three-stage techno-economic framework designed to enhance the exploitation of flexible capacities from demand-side resources such as Internet-of-Things (IoT)-Enabled Appliances (IEAs), Battery-Integrated Rooftop Solar Panels (BIRSPs), and Electric Vehicle (EV) smart charging systems in the local flexibility market. The proposed framework operates in three stages. First, smart homes with IEAs, BIRSPs, and smart charging systems assess their flexibility and report it to their Microgrid (MG) operators. Next, MG operators optimize strategies to maximize market returns and report capacities to the Distribution System Operator (DSO). Finally, the DSO manages flexibility transactions based on MG inputs. A Stackelberg game theory model using a gradient-based method updates the coupling variables between market parties, ensuring convergence in the second and third stages within a decentralized space with limited information sharing. Implemented on a modified IEEE 69-node distribution system, the model fully utilizes the potential of smart homes, including IEAs, BIRSPs, and smart charging systems in the local flexibility market. It reduces the Upstream Network (UN) share in the local flexibility market by 56.86% and decreases DSO costs for energy balancing by 22.36%.

Index Terms- Flexibility markets; Microgrids; Smart homes; Electric vehicles; Internet-of-things; Renewable energy resources

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