Optimal Mechanisms for Demand Response: An Indifference Set Approach

Stefan Wager

Abstract :
The time at which renewable (e.g., solar or wind) energy resources produce electricity cannot generally be controlled. In many settings, consumers have some flexibility in their energy consumption needs, and there is growing interest in demand-response programs that leverage this flexibility to shift energy consumption to better match renewable production -- thus enabling more efficient utilization of these resources. We study optimal demand response in a model where consumers operate home energy management systems (HEMS) that can compute the "indifference set" of energy-consumption profiles that meet pre-specified consumer objectives, receive demand-response signals from the grid, and control consumer devices within the indifference set. For example, if a consumer asks for the indoor temperature to remain between certain upper and lower bounds, a HEMS could time use of air conditioning or heating to align with high renewable production when possible. Here, we show that while price-based mechanisms do not in general achieve optimal demand response, i.e., dynamic pricing cannot induce HEMS to choose optimal demand consumption profiles within the available indifference sets, pricing is asymptotically optimal in a mean-field limit with a growing number of consumers. Furthermore, we show that large-sample optimal dynamic prices can be efficiently learned via an algorithm that only requires querying HEMS about their planned consumption schedules given different prices. We demonstrate our approach in a grid simulation powered by OpenDSS, and show that it achieves meaningful demand response without creating grid instability.