Optimal control of flexible consumers' energy demand through dynamic prices

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Abstract: As the penetration of renewable energy increases, the flexibility of the energy production decreases, and the risk of imbalances becomes higher. Although this can be mitigated by either increasing capacity and culling excess production or storing the energy in batteries or green chemicals, there is also a large potential for exploiting flexibility at the demand-side, which may be significantly less expensive and resource-intensive. In this work, we consider flexible consumers that are unlikely to offer direct control over their energy consumption, e.g., private households, power-to-X plants, or carbon capture facilities, but instead react to changes in intraday energy prices (price-responsive consumers). We use a previously developed demand-response model to describe how the aggregate demand of a consumer population reacts to prices, and the key contribution is that we formulate an economic optimal control problem (OCP) for *simultaneously* determining how much energy to purchase for the consumers and what the dynamic price for the consumers should be. Specifically, a dynamic price sequence is computed for 24 h (a full day) and communicated to the consumers 12 h in advance, such that they can schedule their consumption accordingly. In this work, we analyze the solution to the OCP based on numerical case studies, and we discuss the challenges associated with extending the formulation to include stochastic demand response models.

Keywords: Optimal control, demand response models, indirect control, demand-side flexibility.

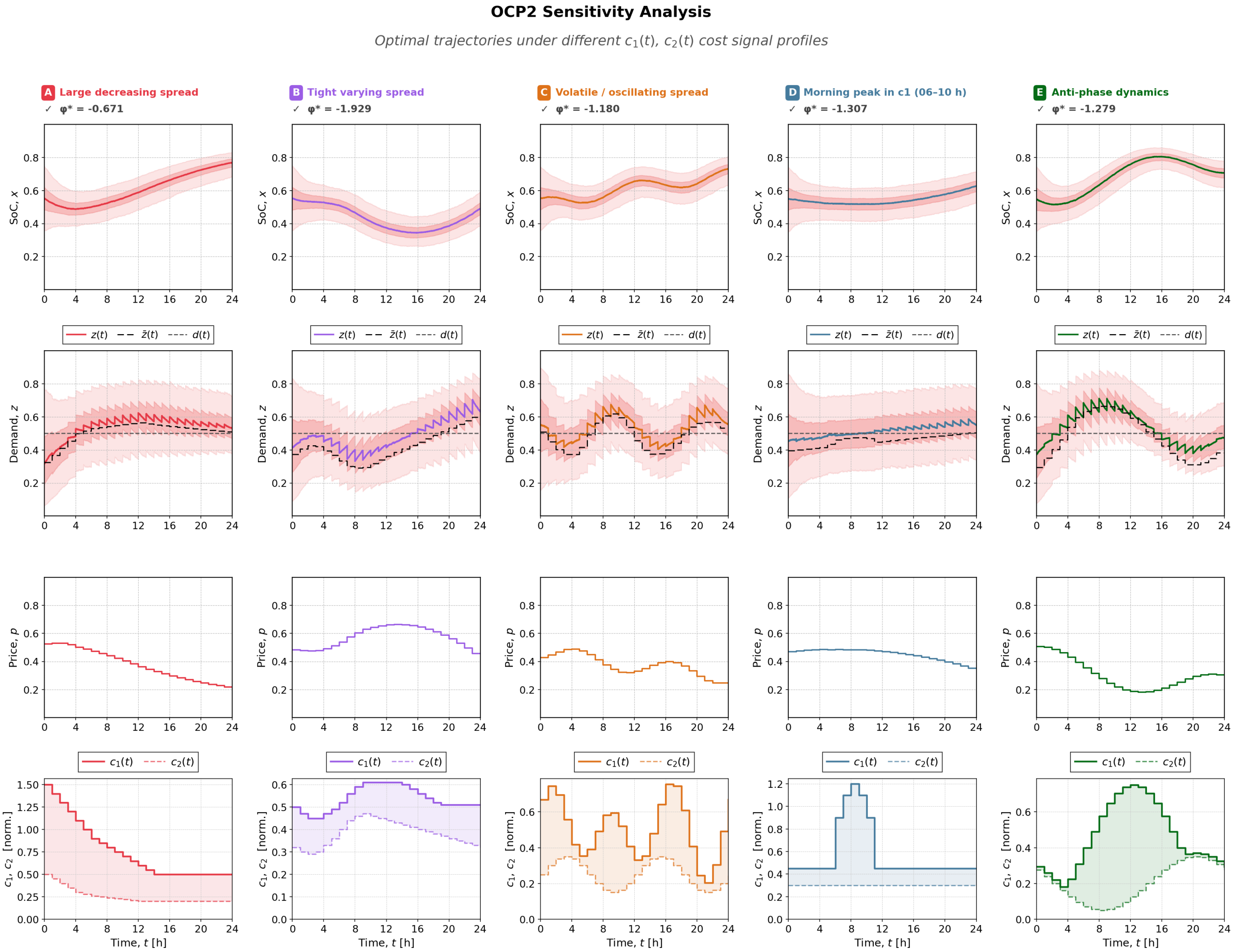

Fig. 1. Each column shows a numerical solution to the proposed optimal control problem for different day-ahead and intraday prices used in the economic objective function. For each solution, we use Monte Carlo simulation to approximate the distribution of the aggregate state of charge and demand of the consumer population. Top: State of charge (SoC), x. Second from the top: Actual, z, (solid) purchased, $\bar{z}$, (black dashed) and nominal, d, (grey dashed) demand. Third from the top: Dynamic prices, p, for the consumers. Bottom: Day-ahead, c_2, (dashed) and intraday, c_1, (solid) prices. The two top rows show the mean (thick line), 50% confidence interval (dark shaded area), and 95% confidence interval (light shaded area), and the dashed line in the second row shows the nominal demand. The shaded area in the bottom row only serves the purpose of visually emphasizing the difference between the day-ahead and intraday prices. Finally, the values of the economic objective function, φ^*, are shown at the top of each column, and the lower values represent higher profit.