**[*HOW TIME-OF-USE RATES AFFECT THE ARBITRAGE POTENTIAL IN A LOCAL PEER-TO-PEER ENERGY MARKET*]**

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## Overview

With growing penetration of distributed resources and the development of microgrids, many researchers have paid attention to emerging local peer-to-peer (P2P) electricity markets1,2. Some researchers have proposed several approaches to determine the price in the local market3,4. However, the process in which tariff design, such as Time of Use (TOU) rate and flat rate, affects the local market price formaton is not well understood. TOU rate could incentivize the adotion of solar panels5 and the battery storage6 if looking the main grid only. To date, these studies has not considered the P2P local market and how it could further affect the adoption of storage, demand response resources and energy efficiency measures like heat pumps.

In this paper, we explore the effect of tariff design on the adoption of energy storage in a local P2P market. First, a price forward curve is constructed based on the electricity demand of the local community which remains connected to the retailer’s network. We then compare local price curve under TOU and flat rates, and assess how it could affect storage adoption by changing energy arbitrage potential in a local P2P market, further guding the way of tarrif design and microgrid management in the energy transition towards a decentralized system.

## Methods

We assume a 100-household community that is connected with the main grid and owns abundant distributed generation resources including, but not limited to rooftop solar PVs, wind turbines and disel generators. Households can purchase/sell the electricity to/from the grid or to/from the local P2P market. Pecan Street Inc. provides the 2018 historical hourly electricity demand data of households in Austin. Thus, we adopt a simplified tariff in Austin. Based on the average monthly electricity consumption in the community, the tiered pricing is simplified as the average price of the tiers. The electricity sold to the grid is priced similar to how Austin utility calculates the Value of Solar, a feed-in tarrif for behind-meter solar PV, which includes energy value, transimission value and the environment value. The differences in our simulation is that we only use the energy value, because the electricity sold to the grid still needs transmission and may not have environment value if coming from disel generators.

The price projection could be constructed through statistic approaches utilizing the market data or based on the fundmental dynamics of supply and demand. Here we make a strong assumption that the electricity price curve would follow the same shape as the demand curve. The similarity is determined by the squared differences between the two curves. The price in the local market should not be higher than the tariff of the main grid, otherwise customers would purchase electricity from main grid. Similarly, the price should not be lower than the feed-in tariff, otherwise the producer would sell to the main grid not the local market. The estimation of the local price curve become the following optimaziation problem (Equation 1) to minimize the shape differences between the local price and demand. is the price in local market at hour t and is a standarlized local demand at hour t. denotes the price of the main grid at hour t and is the feed-in price of the main grid at hour t. The standardization of demand follows Equation 2. We assume that the hourly demand is a perfect forecast and do not attempt to project it by ourselves. By solving the optimaziation problem each day for a whole year, we get the year-long estimated price

Equation 1 s.t.

Equation 2

Equation 3

Once we get the hourly price by solving Equation 1, we use two metrics to assess the energy arbitrage potential in the local market. The first one is the off-peak-peak price (OP/P) ratio. If the round trip efficiency is higher than OP/P ratio, it is possible to earn profit through arbitrage as indicated in Equation 3. Another metric is the total price differences between the hourly price and the average daily price which indicates the largest profit potential of a given storage system. As they are caculated everday, we would have 365 of each indicator, which will then be summarized in density plots and duration curves to show their distribution over the year. We recongnize some storages can store more than one day but most of the current battery storage systems still operate on a diurnal cycle.

## Results

Figure 1 presents the price curves under two tariff designs in four selected days to represent different seasons. The local price curves generated by two tariff design are similar in summer. The TOU rate usually limits the local price in the evening since the TOU rate is based on the system demand, but the household may still consume a lot during the night and early morning. In the spring and autumn, the TOU would incentivize a higher peak price in the local market compared to a flat rate design.

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Figure 1 Local price curve.a)Spring, Apr 17th;b)Summer, Jul 17th;c)Autmn, Oct 17th;d)Winter, Jan 17th

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Figure 2 Energy arbitrage potential indicators

## As for the energy arbitrage potential, we found that the TOU rate would allow a energy storage with a round trip efficiency as low as 30% to earn some profits in 47 days of the year based on the duration curve for the OP/P ratio (Figure 2), but in flat rate design, in 100% of the duration the OP/P ratio is higher than 0.3. The total price differences over the year under the TOU design (153.7$/kWh) is also slightly higher than the flat rate design (150.5$/kWh).

## Conclusions

With the TOU rate, the local market would usually have lower electricity price in the evening and morning comparing with a flat rate. Although the TOU may also limit the high prices in non-peak hours, like in the winter morning, it generally provide a larger potential for energy arbitrage and thus, it could attract more energy storage systems in the local market. Moreover, TOU also enable energy storage with a low efficiency like hydrogen system, to earn profit in some days of the year, showing a possible diffusion pathway in the community..

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