Scaling Distributed Energy

Storage for Grid Peak Reduction Summary

**Abstract**

The paper wanted to store energy during inexpensive off-peak periods and using that energy during inexpensive peak periods. Variable rate pricing provides only a weak incentive for distributed energy storage and does not promote its adoption at scale. Surcharge encourages consumers to flatten their demand than to shift to lower periods. PeakCharge is a peak-aware charging algorithm in hopes to reduce upfront capital cost (requires less storage capacity per consumer) and increase energy storage’s ROI (migrates to free riding) and aggregate storage capacity within 18% of an optimal centralized system.

**1. Introduction**

Large Upfront Capital Costs

Low pricing during off-peak nighttime; high pricing during daytime period, shifts all consumers demand to off-peak.

Rebound Peaks and Grid Instability

All consumers to charge during off-peak will trigger rebound peaks if prices do not charge to reflect the resulting increases in off-peak demand. The rebound will result in increase than decrease causing the peak to increase 120%.

Uncertain Return-on-Investment

To avoid rebound; electricity rate in real-time. This will result in peak and off-peak price narrow, reducing energy storage’s benefits. Once the peak/off-peak price differential is not large enough to compensate for the conversion losses from storing energy in batteries, there is no benefit to using energy storage.

Socialized Benefits and Free Riders

The annual cost to install and main battery-based energy storage is much higher than the annual saving on an electric bill. Variable rate pricing plans provide a weak, non-optimal incentive for energy storage.

* 1. **Contributions**

Designing a charging algorithm and pricing plan where individual consumers flatten their own demand. Downside is more aggregate energy storage capacity to flatten grid demand than the minimum required using a centralized approach.

Scalable Design

Existing charging algorithms and pricing plans cannot simultaneously minimize an electric bill and ensure grid stability at scale. However, PeakCharge will optimize a consumer’s electricity costs in the presence of a peak demand surcharge.

Closed-loop Experimentation

Cost to regenerate electricity as demand rises, to dynamically compute electricity rates based on demand. Algorithm reacts to the rates, alters demand and then changes the rate.

Grid- and Consumer-scale Evaluation

“Greedy” approach that stores as much energy possible during low-price periods. Reduced upfront capital costs and increases ROI.

**2. Overview and Approach**

Need to limit energy storage capacity which annually are $100-$200 per kWh. Also need to consider the ~20% conversion loss from storing energy in batteries.

**2.1 PeakCharge Architecture**

PeakCharge encourages building to flatten their demand rather than simply shift large amounts of demand from daytime to nighttime. SmartCharge simply shifts the original peak demand to the off-peak periods to minimize electricity costs.

**2.2 The storage Adoption Cycle**

Consumers shift demand using energy storage, the difference between the grid’s peak and off-peak demand narrows resulting in a flatter grid demand profile. Prices also flatten to reflect the new demand distribution but flat prices eliminate the incentive to use energy storage, which causes demand to vary again and the cycle to repeat.

**2.3 An Optimal Approach**

The optimal approach would be to shift aggregate grid demand such that it was the same-equal to average demand-all the time. The result, the minimum energy capacity necessary to flatten demand is equal to the maximum capacity ever required to charge or discharge the batteries to sustain the average.

**3. Scalable Design**

Greedy algorithm could result in large rebound peaks if price do not react to the changing demand, grid instability if price react to slow, and finally no benefit to consumer if react to quickly. If consumers flatten their own demand, then grid demand will also flatten.

**3.1 Benefits of a Peak Demand Surcharge**

Higher peak demand surcharge and lower rates will penalize consumers with energy storage less than consumers without it. Existing variable rate plans consumers with a battery must choose to either use it to reduce their electricity bill or preserve privacy, but not both.

**3.2 Drawbacks of a Peak Demand Surcharge**

To flatten, consumers need to install more energy storage capacity than necessary.

**4 Peak-Aware Charging**

Linear Program is optimal if future demand is known which SmartCharge uses. LP is hard at predicting next-day demand at the granularity of an hour is much less accurate than over the multi-hour period. Charging the battery at its maximum rate overnight, regardless of the predictions of next-day demand, accounts for the vast majority of the saving in SmartCharge and other systems.

**4.1 Optimizing for the Peak**

Peak-centric algorithm works well as long as the target average is near the actual average power, and the storage capacity is large enough to flatten demand. If target is too small, will not store enough energy to reduce the peak by its maximum amount. To large will store more energy than necessary throughout the day. Average power predictions over long time periods tends to be much more accurate than demand predictions over short time-scales far into the future.

**4.2 Optimizing for Peaks and Variable Rates**

High peak demand surcharge the algorithm should behave like the peak-centric algorithm, and with a low peak demand surcharge the algorithm should behave greedy.

XmaxelossChighT − XmaxClowT > XmaxP

High and low, where Chigh is the cost per kWh during the high rate period and Clow is the cost per kWh during the low rate period. In addition, T is the length of the low-price period, P is the cost per kWh of usage during the peak hour each day, eloss is the energy conversion loss as a percentage stored energy (typically 80% in practice), and Xmax is the maximum charging rate of the battery.

Left side is the maximum monetary benefit of greedily charging the battery at its maximum rate during the low-price period and then discharging it during the high-price period, while the right side is the cost of peak demand surcharge from charging the battery at its maximum rate.

* If the electricity rate is low and demand is below average, then greedily charge at the maximum rate if (1) holds, else charge at a rate to sustain the target average demand.
* If the electricity rate is low and demand is above average, then greedily charge at the maximum rate if (1) holds, else discharge at a rate to sustain the target average demand.
* If the electricity rate is high and demand is below average, then greedily discharge at the full rate (bounded by the building’s demand) if (1) holds, else do nothing.
* If the electricity rate is high and demand is above average, then greedily discharge at the full rate (bounded by the building’s demand) if (1) holds, else discharge at a rate to sustain the target average demand.

**4.3 Summary**

Enforcing a limit on the battery-charging rate is a simple way to ensure grid stability and prevent rebound peaks, even using greedy charging.

**5. Evaluation**

Closed-loop will be determined by each hour of each day from the same hour on the previous day and the demand-cost function. (Day-Ahead Real-Time)

**5.1 Grid-scale Effects**

TOU pricing scales slightly better than DART because the closed-loop pricing results in very low rates when consumers are not charging, which reflect in the next day’s prices. TOU rate does not change.

Peak-aware algorithm is not able to perfectly flatten demand due to inaccuracy in choosing target average, which may result in high peaks if a home’s battery is empty during a period of high demand.