Peak Shaving in Columbia Campus

EAEE 4220 Fall 2022 Project 2

1 Introduction

Columbia University, like most commercial buildings in New York City, pays its electricity bill in two parts. The first part pays for the energy used by the university, and Columbia University pays its energy consumption at a fixed rate of \$0.13/kWh using a demand-supply contract. The other more significant part is the peak demand charge, which Columbia University pays monthly based on its peak demand. More specifically, Columbia University follows the ConEdison SC9 Rate II tariff. The peak demand for any single billing cycle is based on the highest two consecutive 15-minute intervals of demand. The rate is as follows

- For the months of June, July, August, and September - considered "on-peak" is on a three-level "ratchet"
  - Monday through Friday, 8 AM to 6 PM (high/low tension service) \$9.15 per kW
  - Monday through Friday, 8 AM to 10 PM (high/low tension service) \$18.44 per kW
  - All hours of all days (low tension service only) \$16.66 per kW
- Charges applicable for all other months, considered "off-peak" are on a two-level ratchet
  - Monday through Friday, 8 AM to 10 PM (high/low tension service) \$13.96 per kW
  - All hours of all days (low tension service only) \$4.21 per kW

The peak demand charge rates are stackable based on the time period.

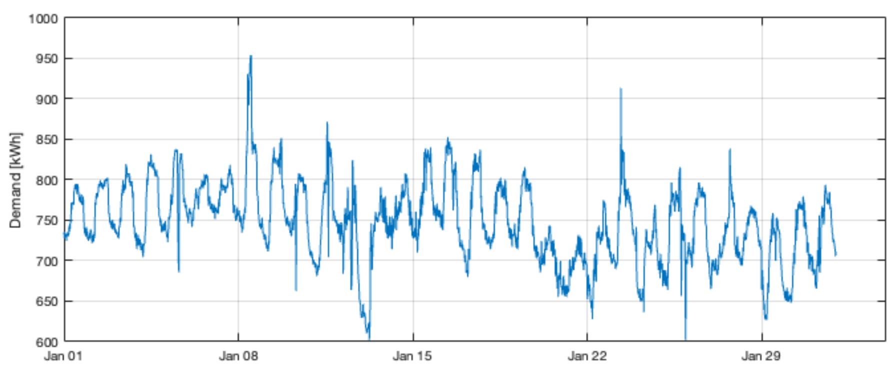

Figure 1: Columbia campus demand January 2018.

For example, the highest demand of January 2018 occurred on Jan 08, 11:45 AM - 953.28 kWh and 12:00 PM - 951.84 kWh. Thus the peak demand in kW over this 30-minute window is 3810.24kW, and the peak demand charge in January is \$13.96+\$4.21 = \$18.17/kW. Therefore, the peak demand charge for January 2018 is \$69,232.06.

The university is considering installing an energy storage device on the campus to reduce its peak demand charge. The storage will discharge during peak demand periods to reduce peak demand charge, and recharge during off-peak periods which will not incur additional peak demand charge.

The university has two candidate storage technologies to install on campus: a lithium-ion battery energy storage that costs \$300/kW for its power rating, and \$200/kWh for its energy rating; the other technology is a thermal energy storage that costs \$500/kW for its power rating, and \$50/kWh for its energy rating. For example, a 100 kW/200 kWh storage would cost \$70k for lithium-ion, and \$60k for thermal storage. Due to limited space and construction requirements, only ONE of the two technologies can be installed. Both technologies have a rated lifetime of 10 years.

The lithium-ion battery has a four-hour energy duration, while the thermal storage has a 12-hour energy duration. For example, a 1 MW lithium-ion battery must have an energy capacity of 4 MWh; while a 1 MW thermal storage must have an energy capacity of 12 MWh.

The lithium-ion battery has 95% single-trip efficiency, while the thermal energy storage has 70% single-trip efficiency. For example, if thermal storage charged 1 MWh energy, it will only have 0.7 MWh in its storage, and only be able to discharge 0.49 MWh. The efficiency loss is thus 0.51 MWh.

Besides the storage cost parameters, you are given the total demand profile of the campus over the year 2018 and 2019. The data records the kWh energy consumption over 15-minute intervals.

2 Project Objective

You are assigned the task to design this storage project for the university, specifically:

- What kind of technology and what storage power and energy rating should be installed on campus?
- How should the storage be **realistically** operated to provide peak shaving? Your final solution should not assume Columbia has perfect future demand predictions.
- How much cost saving can the university realistically expect per year from performing peak shaving with the installed storage project counting in
  - Peak demand charge reduction.
  - Cost of efficiency loss (\$0.13/kWh).
  - NPV (net present value) cost of storage installation over a 10-year period and an annual discount ratio of 8%.

You must document your analysis in a report including quantitive analysis and your final recommendations.

3 Directions

A deterministic optimization formulation to minimize the utility bill is provided in the appendix. Your first step should be implementing this optimization using the provided data and conducting a baseline proof-of-concept analysis to see how energy storage could help to reduce the cost of electricity for Columbia. Note that the peak demand charge is monthly so you should perform the optimization every month.

However, note that this is a **deterministic** formulation which assumes the operator knows the perfect future information of demand which is not possible in practice. Therefore, after finishing the baseline analysis, your primary effort should focus on how to design operation strategies to operate storage without using the actual future demand data. A few **example** directions

- Try to minimize daily peak demand instead of one month directly;
- Record the maximum demand of this month so far and try not to exceed it;
- Use yesterday's demand as today's demand forecast;
- Use the same-day demand from last year as today's demand forecast;
- Use prediction methods such as ARIMA to predict demand

Of course, you should think about other approaches and see which one provides you with the best cost savings.

Finally, after you settled on a satisfactory peak-shaving approach, the last step is to determine the optimal capacity of the storage. Although the planning problem is usually difficult to solve, in this project you only have a single planning variable, which is the power capacity of the storage (the energy capacity is a fixed ratio to the power capacity). In this case, a **naive** approach is to simply try different possibilities and conclude the best options. You can also think about some better approaches such as the bisection method.

4 Appendix - Peak shaving formulation

Energy storage parameters:

- η single-trip charge and discharge efficiency;
- P storage power rating
- E storage energy rating

Campus demand profile

- D_t campus demand over time period t

Decision variables

- d_t storage discharge power
- q_t storage charge power
- e_t energy stored - storage state-of-energy
- p peak demand

Peak demand and energy prices

- C energy cost of electricity in \$/MWh
- B peak demand charge of electricity converted to \$/MWh

A deterministic peak shaving optimization problem can thus be formulated with an objective that minimizes the total electricity bill cost including the peak demand charge and energy cost

$$\min_{p_t, q_t} Bp + C \sum_t (D_t - d_t + q_t) \tag{1}$$

subjects to the power rating constraints

$$0 \leq d_t \leq P \tag{2}$$

$$0 \leq q_t \leq P \tag{3}$$

The state-of-charge constraint

$$e_t - e_{t-1} = q_t\eta - p_t/\eta \tag{4}$$

$$0 \leq e_t \leq E \tag{5}$$

And the peak demand identification over two consecutive demand periods

$$p \geq D_t - d_t + q_t + D_{t+1} - d_{t+1} + q_{t+1} \tag{6}$$