Arcadia
Hackathon 2022

Incorporating DERs (Solar & Storage) into Signal for Optimized Charging

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OVERVIEW

Optimization across DER products is complicated. We have heard from Enterprise prospects ranging in size and from EV Auto OEMs to smaller charging companies that optimizing charging based on the end user's tariff, makes sense but the natural next question is... what about if the end-user has solar or a battery - can you optimize for that?

This document explores solutions that cover 3 cases:

1. Residential use case - considers cost optimization and battery life
2. Commercial use case - considers tariff, solar generation, battery energy storage, EV charging, and peak demand charges to identify the cost optimized solution
3. EV fleet charging use case

ASSUMPTIONS / PROBLEM SETUP

Residential site consists of:

- One EV requiring ~4900 kWh of charging a year (bullets below) with max charging rate of 7 kW (source)
  - 0.346 kilowatt-hours of electricity per mile driven (average of 231 different EVs)
  - 14,200 miles/year for an average car (Kelly Blue Book)
  - THEREFORE, ~4913 kWh/year for an EV
- Solar panel system rated at (?) kW
- Battery storage (optional) with maximum capacity of (?) kWh
- Tariff schedule

  - kWh charges
  - Most EV drivers are on TOU rates varying based on time of day
  - Potentially, monthly peak demand charges
- House with base load of (?)

OPTIMIZATION FORMULATION

Section for different optimization ideas:

Idea 1: Net metering for EV owners (no solar or storage)

Currently EV solution will advise on when to charge your EV based on when power is the cheapest (using Genability's rate schedule database). Next question - how to incorporate solar or battery storage?

Optimize EV charging with solar & storage

$$Minimize\ (Cost) = intervalRates \cdot (intervalUsages + intervalCharges - intervalDischarges)$$

$$+ \ degradationSwitchCost * \sum_t 1[intervalCharges_t \ != intervalCharges_{t+1}]$$

$$+ \ degradationUsageCost * \sum_t 1[intervalDisharges_t > 0]$$

Subject to constraints:

$\sum_{t=1}^{T} intervalCharges_t = capacity$ (if electric vehicle, must end charged)

$\sum_{t=1}^{t'} intervalCharges_t - intervalDischarges_t \le capacity\ for\ t' \in \{1, 2,..., T\}$ (can't charge past max capacity)

$\sum_{t=1}^{t'} intervalCharges_t - intervalDischarges_t \ge 0\ for\ t' \in \{1, 2,..., T\}$ (can't discharge past 0)

Idea 2: Storage + Peak Demand (Commercial)

Required Inputs to the Optimization

1. Energy available in battery storage

2. Predictions for
    a. hourly load profile
    b. hourly solar generation profile
3. Energy available in storage battery

Solar plus storage

Cost:

- Cost of charging + opportunity cost of using stored energy
- Nighttime - it's cheaper than daytime now. If you have stored energy, should you use the storage or save that for tomorrow?
    - Forecast says it will be sunny. Charge to minimum now, and save the rest for later
    - Forecast says it will be cloudy. Don't use storage bc we will need it tomorrow for base load
- Daytime
    - If you are nearing the monthly peak, don't charge or charge just enough, and store the rest for later

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Objective:

$$Minimize\ cost\ =\ cost\ of\ charge\ +\ cost\ of\ peak\ demand\ risk$$

Decision Variable:

Will we charge the EV (value of 1 or 0 for Yes/No) at time *t*, we will call this C_t ⋆

Will we use battery storage? (value of 1 or 0 for Yes/No) at time *t*, we will call this S_t ⋆

Where:

$$Cost\ =\ \sum_{t0}^{t} cents\ per\ kWh\ *\ (C_t * EVChargeDraw)\ +\ \sum_{t0}^{t} cents\ per\ kWh\ *\ (buildingLoad_t\ -\ solarkWh_t\ -\ storagekWh * S_t)$$

Note: Cost of charge can end up being negative if solar is strong, which is actually good for minimization

$$Cost\ of\ peak\ demand\ risk\ =\ \sum_{t0}^{t}(grid\ demand_t\ -\ previous\ peak\ kW)\ *\ peakDemandWeight$$

$$Grid\ demand\ =\ Base\ load_t\ +\ C_t * EVChargeDraw\ -\ forecasted\ solar\ production_t\ -\ storagekW * S_t *$$

Constraints:

1. $EVChargeDraw\ =\ constant$
2. $peakDemandWeight\ =\ constant,\ chosen\ according\ to\ rate\ schedule\ for\ importance$
3. $previous\ peak\ kW\ =\ constant$
4. $\sum_{t0}^{t} EVChargeDraw * c_t = desired\ charge\ amount$ – EV must be charged to desired amount, within the time interval specified
5. $\sum_{t0}^{t} storagekW * s_t \leq total\ battery\ kWh$ – cumulative charge from battery must be less than energy available in the battery
6. $C_t \in (0, 1)$ – charging at time t is either 1 (on) or 0 (off)
7. $S_t \in (0, 1)$ – charging at time t is either 1 (on) or 0 (off)
8. $C_t + C_{t+1} + C_{t+2} + C_{t+3} = 4\ if\ C_t = 1$ – must charge for at least 1 successive hour (assuming 15min increments) to avoid battery degradation

Constants:

1. EV charge draw – amount of kW drawn by charging the EV
2. Previous peak kW
3. Desired charge amount (kWh)
4. Cents per kWh

Assumptions:

1. Battery storage is solar powered only and does not charge while discharging
2. Constant rate of draw from battery

Simulation:

- Collect the following:
  - Solar production curve
  - Base load curve
- Assume the following:
  - Total EV charging requirement of 200kWh (about 2 Teslas to max capacity)
    - https://ev-database.org/cheatsheet/useable-battery-capacity-electric-car
  - Battery storage of 13.5kWh (one Tesla Powerwall)

- https://www.tesla.com/support/energy/powerwall/learn/how-powerwall-works
- Tariff Schedule (LGS-TOU-74) - from Duke Energy Progress in NC
  - kW Demand Charge: Service Rendered During the Calendar Months Of: June through September
  - On-Peak Billing Demand:
    - First 5,000 kW of Billing Demand
      - $23.14 per kW $19.61 per kW
    - For the next 5,000 kW of Billing Demand
      - $22.14 per kW
    - $21.14 per kW All over 10,000 kW of Billing Demand
  - kWh Energy Charge:
    - 4.795¢ per on-peak kWh
    - 4.286¢ per off-peak kWh
  - The on-peak hours are defined as the hours between 10:00 a.m. and 10:00 p.m., Monday through Friday, excluding holidays considered as off-peak.

ADDITIONAL ADD-ONS

1. Battery health & degradation
2. Peak demand charges
3. Grid carbon emissions at time of use
4. Weather forecast
5. Demand response programs from utilities
6. Expansion to commercial site with multiple EVs and more complex tariffs
7. Vehicle array (v_it) and different initial state of charges for each vehicle
   a. P_it - power demand per vehicle
8.

QUESTIONS

Q#	Question	Answer
Q1	Can we assume an all or nothing charge rate for EVs? IE the rate of charging is constant.	

Q2	Are there some residential tariff schedules with a monthly peak demand charge?	Just checked my (Ashley's) power bill, I actually am not charged this for residential bill. I was thinking of a City Hall/government facilities power bill where I had seen this before.
Q3		

Idea 3: Scheduling fleet charging

Indices:

1. t = time, 1 hour intervals. t ∈ [1,...T]

Decision variables:

1. $gridEV_t$ = kWh of charge pulled from grid to vehicle at time t
2. $solarEV_t$ = kWh of charge pulled from installed solar to vehicle at time t
3. $solarExp_t$ = kWh of charge exported from installed solar to the grid at time t
4. $evSOC_t$ = vehicle state of charge at time t, given in kWh
5. $gridCharge_t$ = auxiliary variable: 1 if EV is charged from the grid at time t, 0 otherwise.

Variables:

1. T = hours until departure (tenant input)
2. $evInitCharge$ = vehicle initial state of charge, given in kWh (tenant input)
3. $evSOC_t$ = vehicle state of charge at time t, given in kWh (calculated)
4. $evCapacity$ = max vehicle battery capacity, given in kWh (tenant input)
5. $evChargeRate$ = max charge rate for storage battery, given in kW
6. $solar_t$ = solar production at time t (PVWatts/tenant input)
7. $consumptionCharge_t$ = marginal cost per kWh pulled from the grid at time t - (Genability)
8. NEM_t = negative cost (revenue) for exporting electrons to the grid at time t, (Genability)
9. DR_t = binary for DR bid at time t: 0 if there is a DR event at time t, 1 otherwise (MAP)

Objective function:

Resulting schedule should 1) minimize the cost of electricity pulled from the grid, 2) maximize the revenue from exporting energy back to the grid

$$min \sum_t [(gridCharge_t * gridEV_t) * consumptionCharge_t] - \sum_t [(solarExp_t) * NEM_t]$$

Constraints:

1. Vehicle charging logic - capacity:
    a. $evSOC_0 = evInitCharge$
    b. $evSOC_{t+1} = evSOC_t + gridEV_{t+1} + solarEV_{t+1}, \quad \forall t$
    c. $evSOC_t + gridEV_t + solarEV_t - evExp_t \leq evCapacity, \quad \forall t$
    d. $solarEv_t \leq solar_t, \quad \forall t$
    e. $evSOC_T = evCapacity$
2. Vehicle charging logic - charge rate:
    a. $gridEV_t + solarEV_t \leq evChargeRate, \quad \forall t$
3. Departure constraints
    a. $evSOC_T = evCapacity$
4. Net Metering - solar export constraints
    a. $gridExp_t \leq solar_t, \quad \forall t$
5. DR constraints
    a. $DR_t * gridEV_t = gridEV_t$

Workspace Links

Item	Link
Battery Optimization	https://colab.research.google.com/drive/1Ien4ffekQqia9yE3oCC_lZ2aq2sgJYmI#scrollTo=IgTgG6bwY2tx
Peak Demand + Storage	https://colab.research.google.com/drive/1p20LEuobpGDXN9yyDEZIVV03Kej9v-vX#scrollTo=7egakA5YZ-We

Optimization	