Sizing Behind-the-Meter Energy Storage and Solar for Electric Vehicle Fast-Charging Stations*

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PRESENTED BY

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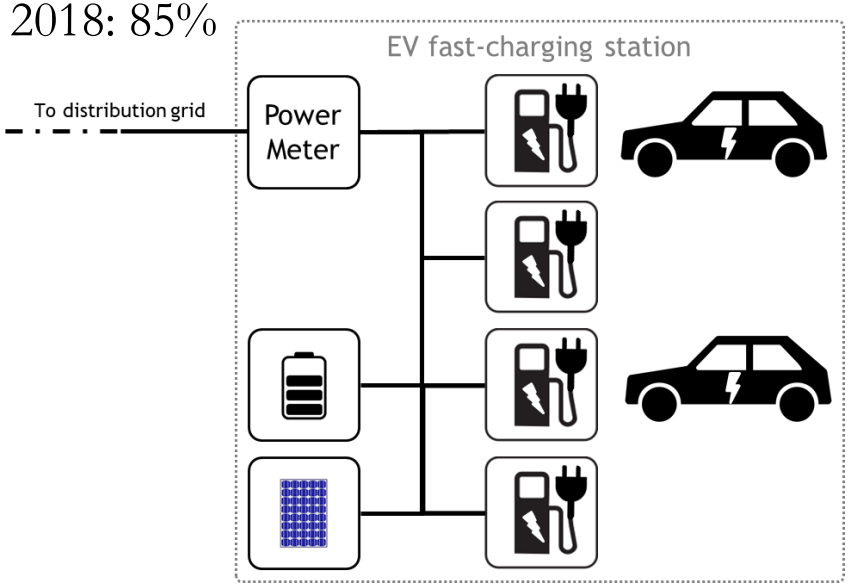
Introduction

Mass adoption of Electric Vehicles (EV) is under way
- Current EV fleet: 0.5%

Projections in 2040
- 57% of passenger vehicles sold
- 30% of world's fleet

Reducing cost of electricity in EV fast charging stations
- Net energy metering (NEM)
  - Opportunities for behind-the-meter (BTM) resources
- Battery energy storage systems (BESS)
  - Declining cost of Lithium-ion in 2010 – 2018: 85%
- Solar photovoltaic (PV) generation

This presentation
- Optimal sizing of PV + BESS
- Evaluation of potential cost savings



Problem formulation

Goal: maximize net present value (NPV) of investment

- Optimal sizing of PV and BESS
- Optimal dispatch of BESS
- Maximize cost savings
- Perfect load forecast – provide upper bound on NPV

$$\max_{q_t^c, q_t^d, \overline{q^m}\,\overline{S}, \overline{q_{PV}}} \sum_{k=1}^{n_y} \frac{R_k}{(1+i_r)^k} - C_{in}, \forall t \in \Omega^t \tag{1}$$

$$s.t.\ (2) - (24)$$

q_t^c,q_t^d	ESS charging,discharging power in time t, kW.
$\overline{q^m}$	ESS rated charge and discharge power, in kW.
$\overline{q_{PV}}$	Rated PV power output, in kW.
R_k	Total cost-saving in year k, in \$.
C_{in}	Total amount invested in PV and ESS, in \$.
i_r	Interest rate for payback.

Problem formulation

Cost savings: baseline (yearly) electricity costs minus cost with BESS and cost of degradation

$$R_k = \sum_{j \in \Omega_k^m} \left(\overline{C_j} - C_j - C_j^b\right), \forall k \in \{1, 2, ..., n_y\} \qquad (2)$$

Costs can include tariffs that feature

- Time-of-use (TOU) charges
- NEM
- Service cost
- Demand charges
- Energy charges

$$C_j = \underline{C} + D_j + E_j, \forall j \in \Omega_k^m \qquad (4)$$

Problem formulation

TOU demand costs

- High peak, low peak and facility charges (last 12 months)

$$D_j = D_j^h + D_j^l + D_j^f, \forall j \in \Omega_k^m \tag{5}$$

TOU energy costs

- High peak, low peak and base rates

$$E_j = p_e^b \cdot e_j^b + p_e^l \cdot e_j^l + p_e^h \cdot e_j^h, \forall j \in \Omega_k^m \tag{17}$$

Degradation costs

- Throughput under warranty
- p_{th} is the ratio between cost of BESS warranty and throughput under warranty

$$C_j^b = p_{th} \cdot \sum_{i \in \Omega_k^t} q_t^d \cdot \Delta t \tag{13}$$

Problem formulation

NEM Policy – utility does not pay for surplus net energy

Battery Operation Constraints

- State-of-Energy (SoE) , maximum charging/discharging

$$0 \leq q_t^c \leq \overline{q^m}, \forall t \in \Omega^t \tag{20}$$

$$0 \leq q_t^d \leq \overline{q^m}, \forall t \in \Omega^t \tag{21}$$

$$0 \leq S_t \leq \overline{S}, \forall t \in \Omega^t \tag{22}$$

$$S_{t+1} = \Delta t \cdot \left(\gamma_s \cdot S_t \cdot + \gamma_c \cdot q_t^c - \frac{q_t^d}{\gamma_d} \right), \forall t \in \Omega^t \tag{23}$$

SoE in start of month

$$S_{t_0} = 0.5 \cdot \overline{S}, \forall t_0 \in \Omega^{t_0} \tag{24}$$

Los Angeles Department of Water and Power (LADWP) tariff A-2

- Large Commercial and Multi-Family Service (4.8kV)
- Demand over 30 kW
- NEM
- TOU

PARAMETERS OF LADWP TARIFF A-2

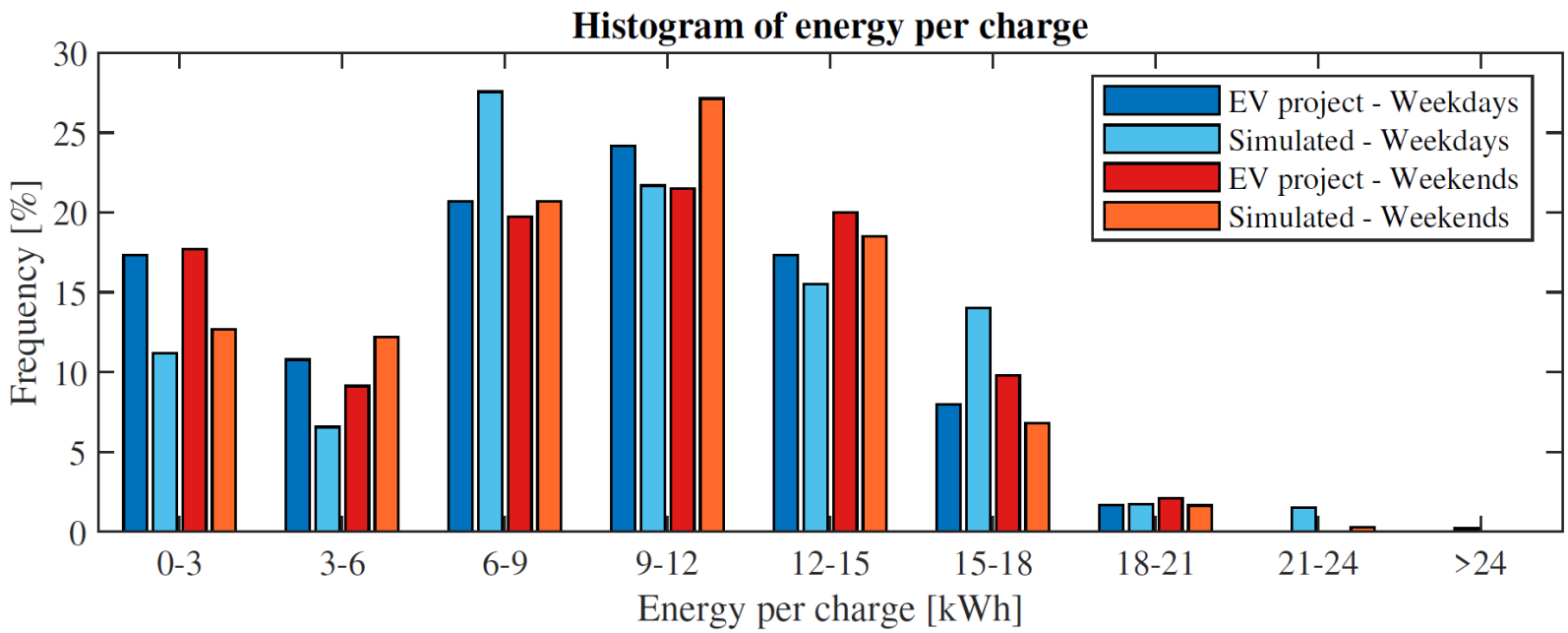
Parameter	Summer	Winter
$\underline{C}$	\$28.00	\$28.00
p_e^{b*}	$\$0.01022/kWh$	$\$0.01395/kWh$
p_e^l	$\$0.05595/kWh$	$\$0.05688/kWh$
p_e^h	$\$0.06322/kWh$	$\$0.05688/kWh$
p_d^l	$\$3.75/kW$	–
p_d^h	$\$10.00/kW$	$\$4.75/kW$
p_f	$\$5.36/kW$	$\$5.36/kW$
$\underline{d}$	$\$30kW$	$\$30kW$

*Includes electric vehicle discount rate of 2.5 cents per kWh.

Hour	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
January	¢1.395/kWh										¢5.688 /kWh			¢5.688/kWh \$4.75/kW				¢5.688 /kWh			¢1.395/kWh			
February																								
March																								
April																								
May																								
June	¢1.022/kWh										¢5.595 /kWh \$3.75 /kW			**¢6.322/kWh \$10.00/kW**				¢5.595 /kWh \$3.75 /kW			¢1.022/kWh			
July																								
August																								
September																								
October	¢1.395/kWh										¢5.688 /kWh			¢5.688/kWh \$4.75/kW				¢5.688 /kWh			¢1.395/kWh			
November																								
December																								

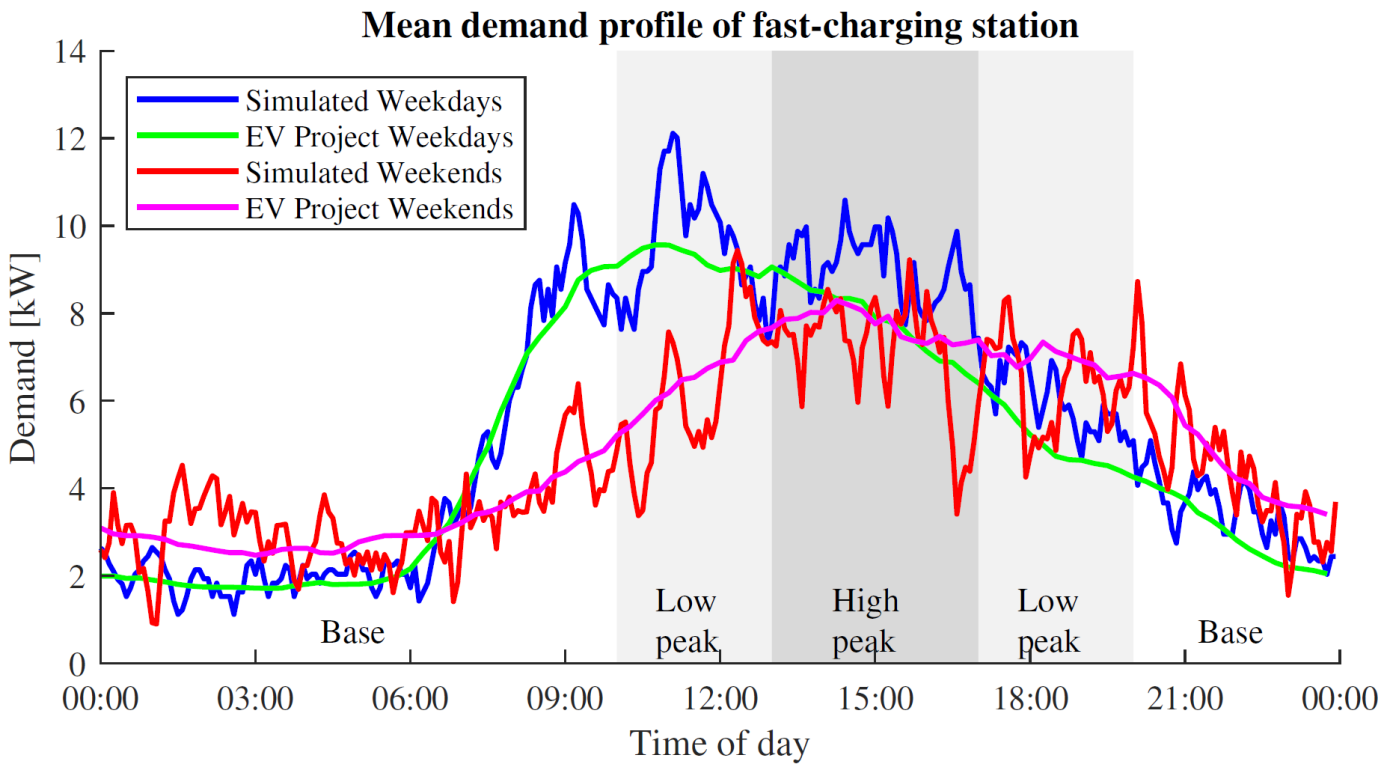
Load profiles

- Based on EV Project data Los Angeles – 2013
- 4x type 2 chargers in station
  - 26.58kW constant load each



Load profiles

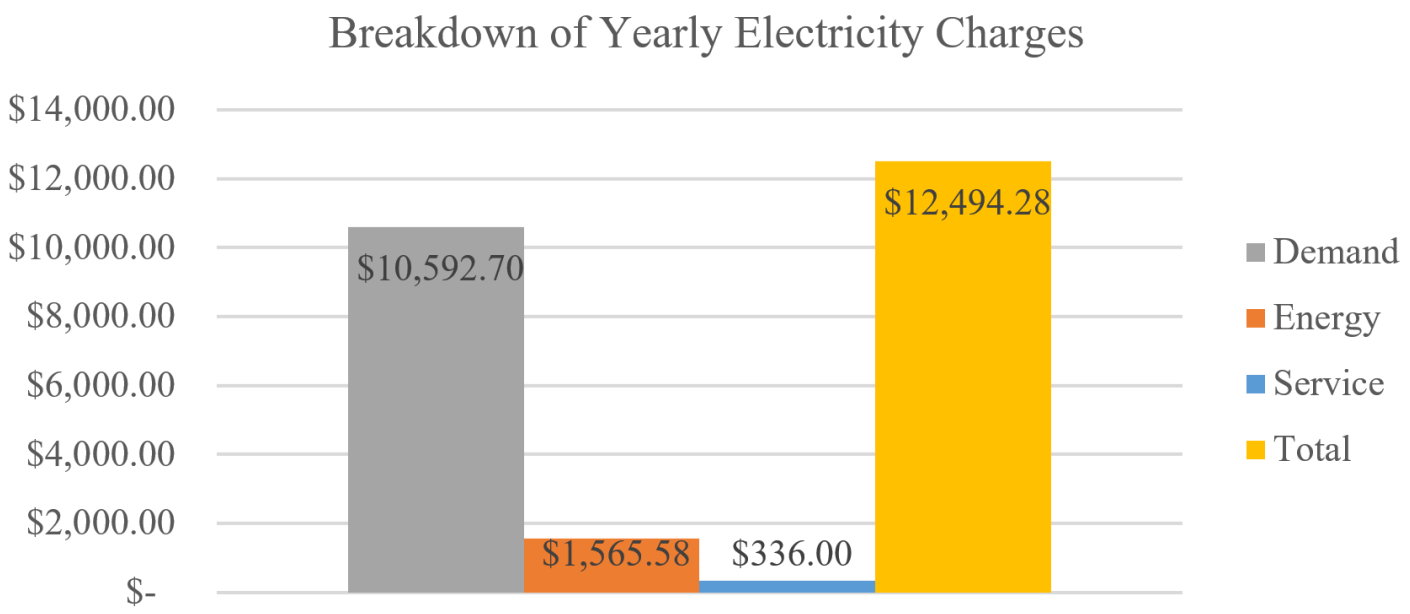
- Zero reactive power costs
- Data synthesized based on statistics of charging
- Distributions of time spent per charging session, energy used in each charging session



Case Study

Cost savings:

- Baseline vs costs with PV and ESS
- Following data, most costs are due to demand-related charges



Case Study

Resulting optimization problem is a Linear Program

Solution using Pyomo, a python-based optimization toolbox

Time resolution of 15 minutes

- It is the same used to calculate demand and energy by meters

Solar profile created using PVWatts

Analysis over 10 years

- Solve for 1 year, assume similar results for coming years
- Assumed constant prices of electricity
- Assumed constant load

Results

Solution of the LP: 298 seconds (GLPK solver)

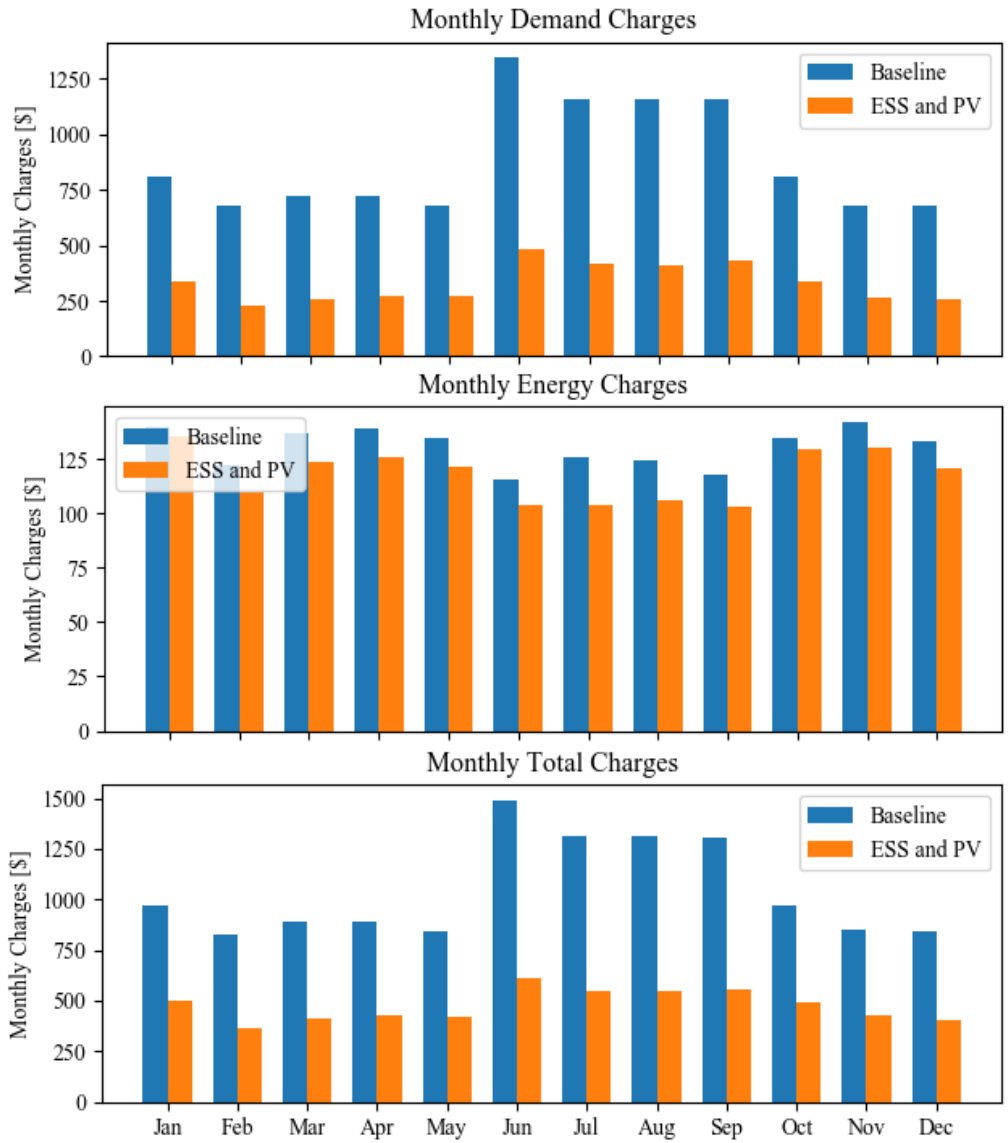
Energy equivalent of 170 cycles/year

No PV!

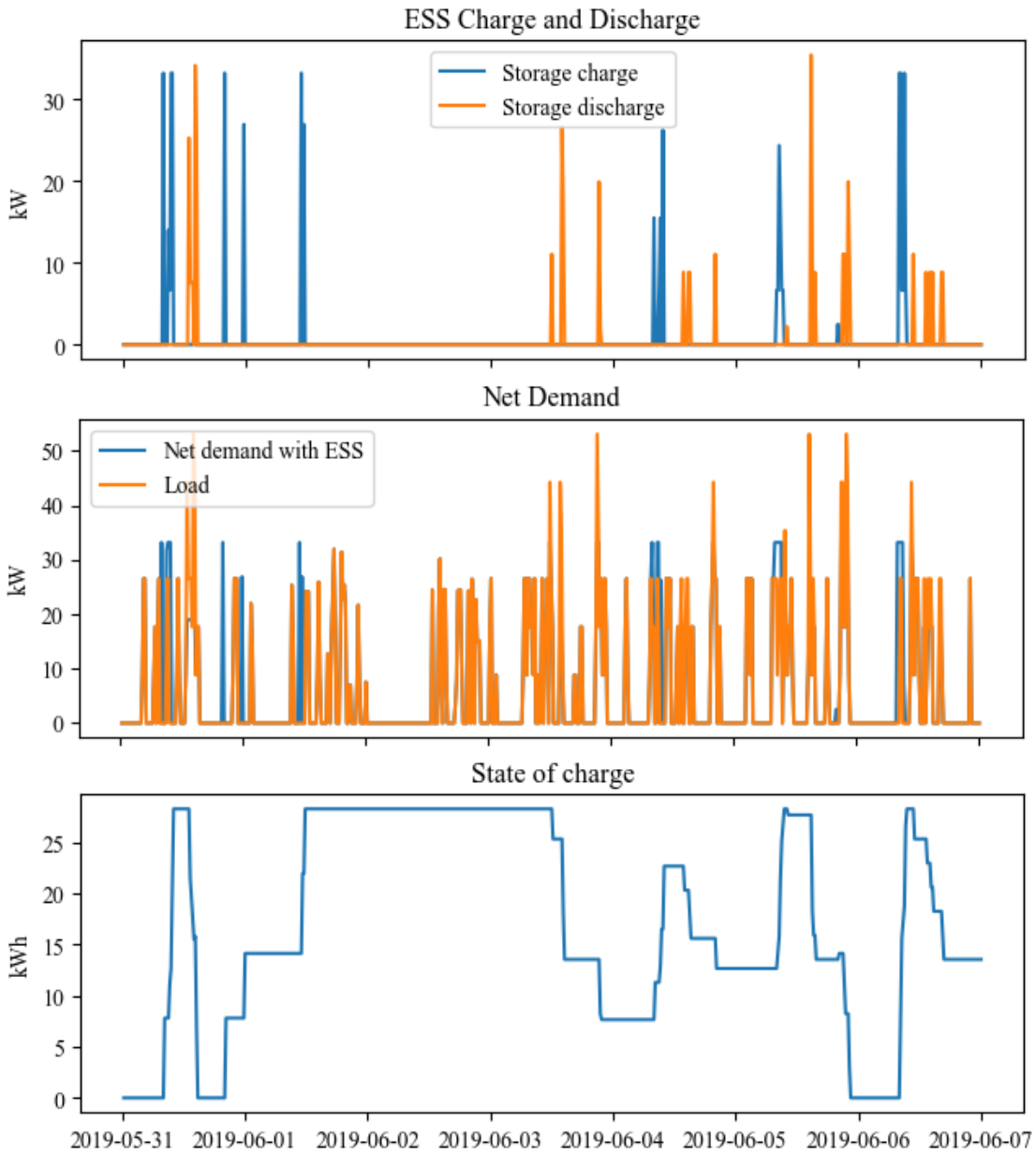
SUMMARY OF OPTIMIZATION RESULTS

	Variable	Value	Variable	Value
	PV cost	\$0.00	ESS cost	\$28551
	ROI	\$22374.50	n_y	10 yrs
	i_r	5%/yr	PV size	0.0kW
	ESS power	46.49 kW	ESS energy	28.26kWh
Base	Max demand	79.70kW	Energy	46.7MWh/yr
	Demand cost	\$10592.70/yr	Energy cost	\$1565.58/yr
	Service	\$336.0/yr	Total cost	\$12494.28/yr
ESS	Max demand	33.21kW	Energy	47.4MWh/yr
	Demand cost	\$3958.35/yr	Energy cost	\$1413.82/yr
	Throughput	4.8MWh/yr	Degradation	\$504.80/yr
	Total electr.	\$5708.17/yr	Total cost	\$6212.97/yr

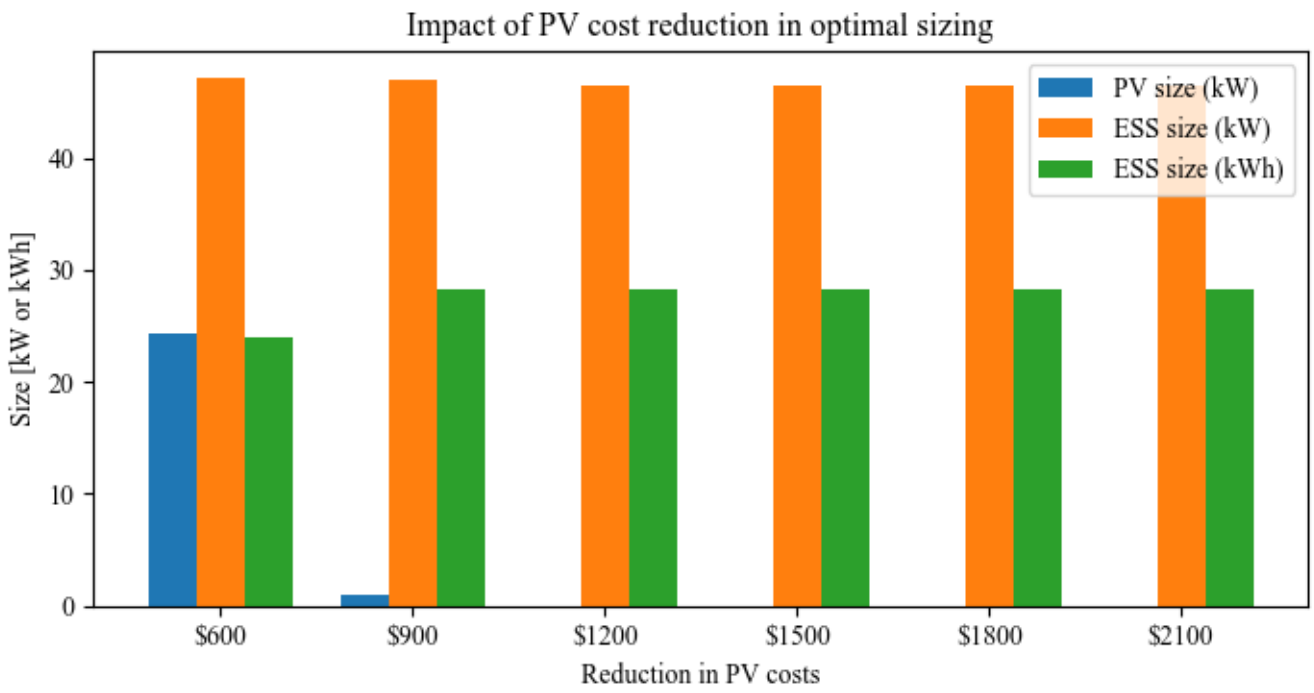
Results


Monthly Demand Charges
Monthly Charges [$]
0
250
500
750
1000
1250
Baseline
ESS and PV
Monthly Energy Charges
Monthly Charges [$]
0
25
50
75
100
125
Baseline
ESS and PV
Monthly Total Charges
Monthly Charges [$]
0
250
500
750
1000
1250
1500
Baseline
ESS and PV
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Results


ESS Charge and Discharge
Storage charge
Storage discharge
kW
0
10
20
30
Net Demand
Net demand with ESS
Load
kW
0
10
20
30
40
50
State of charge
kWh
0
5
10
15
20
25
2019-05-31
2019-06-01
2019-06-02
2019-06-03
2019-06-04
2019-06-05
2019-06-06
2019-06-07

Results


Impact of PV cost reduction in optimal sizing
PV size (kW)
ESS size (kW)
ESS size (kWh)
Size [kW or kWh]
0
10
20
30
40
$600
$900
$1200
$1500
$1800
$2100
Reduction in PV costs

Conclusion

BESS was able to provide significant cost savings
- Baseline costs dominated by demand charges (85%)

PV could not contribute
- PV can reduce energy charges, which are marginal in this problem

PV only makes sense if:
- Cost is reduced
- Charging/occupation rate of chargers increase
- Tariff of energy (kWh) increases significantly

Degradation results in significant reductions in ESS operations

Optimal sizing
- Enough energy to supply for a mean charge
- Enough power capacity to supply 2 chargers

Optimal operation
- Charge battery to restore SoE when demand for chargers and energy costs are low - night/early morning
- Discharge BESS when two or more chargers are being used

Publication

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Thank you!

Q&A?