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SAND2020-9609C

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

2020 DoE OE Energy Storage Peer Review
September 29th-October 1st 2020

PRESENTED BY

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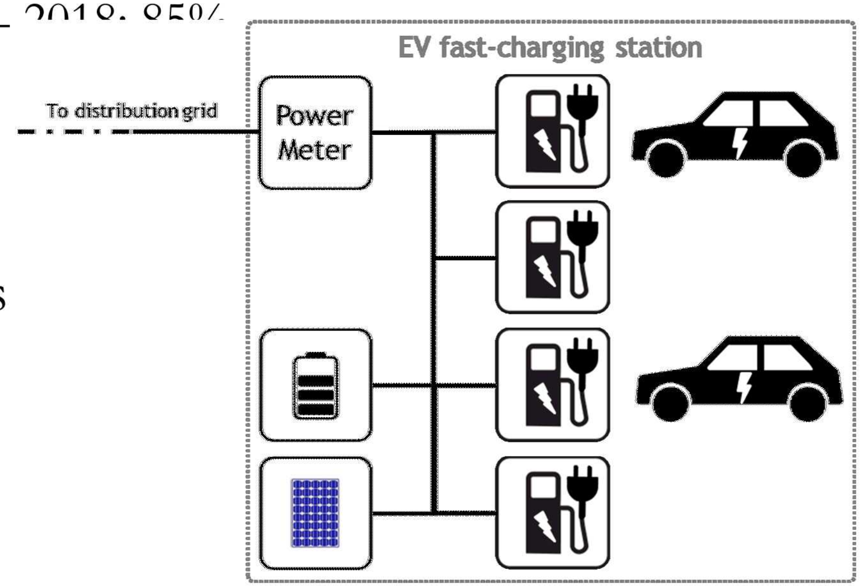
Introduction

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

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

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

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.

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

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

Costs can include tariffs that feature

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

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

TOU demand costs

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

$$D_j = D_j^h + D_j^l + D_j^f, \forall j \in \Omega_k^m \qquad (5)$$

TOU energy costs

- High peak, low peak and base rates

$$E_j = p_e^b \cdot e_j^b + p_e^l \cdot e_j^l + p_e^h \cdot e_j^h, \forall j \in \Omega_k^m \qquad (17)$$

Degradation costs

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

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

Problem formulation

NEM Policy – utility does not pay for surplus net energy

Battery Operation Constraints

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

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

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

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

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

SoE in start of month

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

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.

<table>
<tr><th>Hour</th><th>0</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14</th><th>15</th><th>16</th><th>17</th><th>18</th><th>19</th><th>20</th><th>21</th><th>22</th><th>23</th></tr>
<tr><td>January</td><td colspan="10" rowspan="5">¢1.395/kWh</td><td colspan="3" rowspan="5">¢5.688 /kWh</td><td colspan="4" rowspan="5">¢5.688/kWh $4.75/kW</td><td colspan="3" rowspan="5">¢5.688 /kWh</td><td colspan="4" rowspan="5">¢1.395/kWh</td></tr>
<tr><td>February</td></tr>
<tr><td>March</td></tr>
<tr><td>April</td></tr>
<tr><td>May</td></tr>
<tr><td>June</td><td colspan="10" rowspan="4">¢1.022/kWh</td><td colspan="3" rowspan="4">¢5.595 /kWh $3.75 /kW</td><td colspan="4" rowspan="4">¢6.322/kWh $10.00/kW</td><td colspan="3" rowspan="4">¢5.595 /kWh $3.75 /kW</td><td colspan="4" rowspan="4">¢1.022/kWh</td></tr>
<tr><td>July</td></tr>
<tr><td>August</td></tr>
<tr><td>September</td></tr>
<tr><td>October</td><td colspan="10" rowspan="3">¢1.395/kWh</td><td colspan="3" rowspan="3">¢5.688 /kWh</td><td colspan="4" rowspan="3">¢5.688/kWh $4.75/kW</td><td colspan="3" rowspan="3">¢5.688 /kWh</td><td colspan="4" rowspan="3">¢1.395/kWh</td></tr>
<tr><td>November</td></tr>
<tr><td>December</td></tr>
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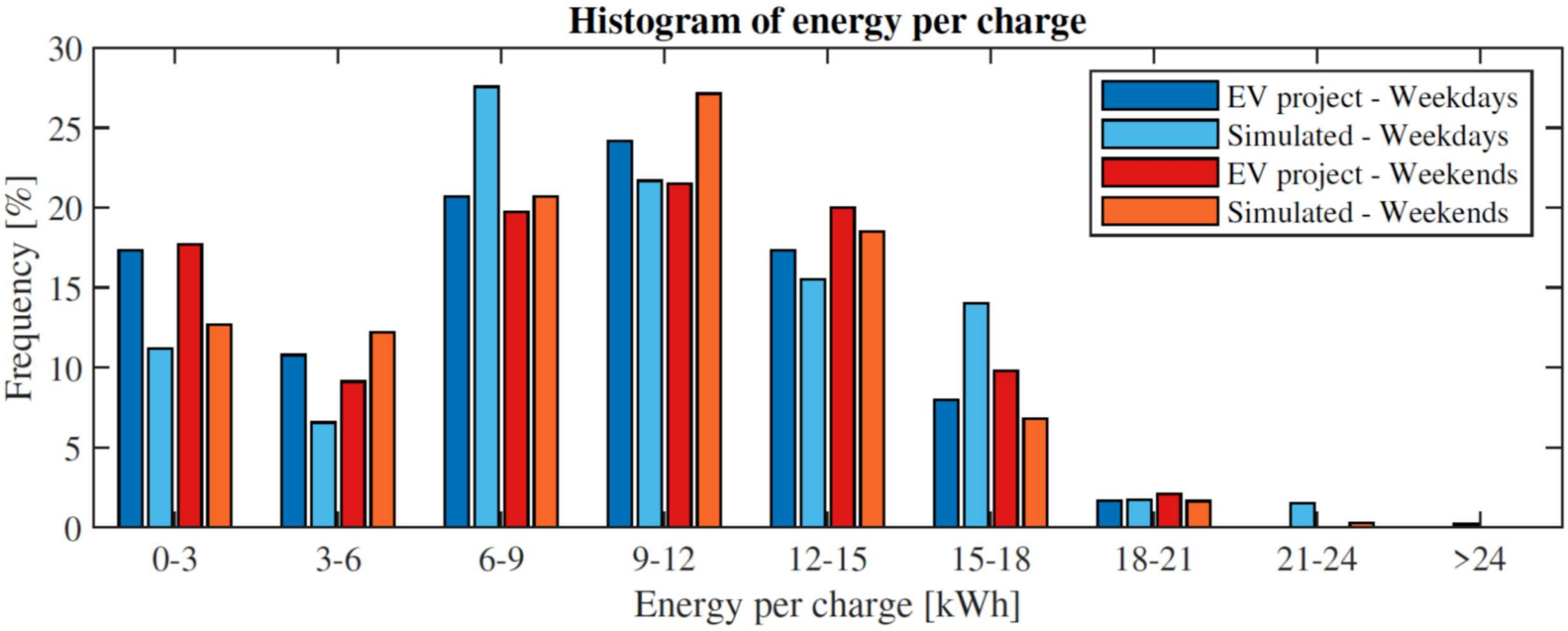
Case Study

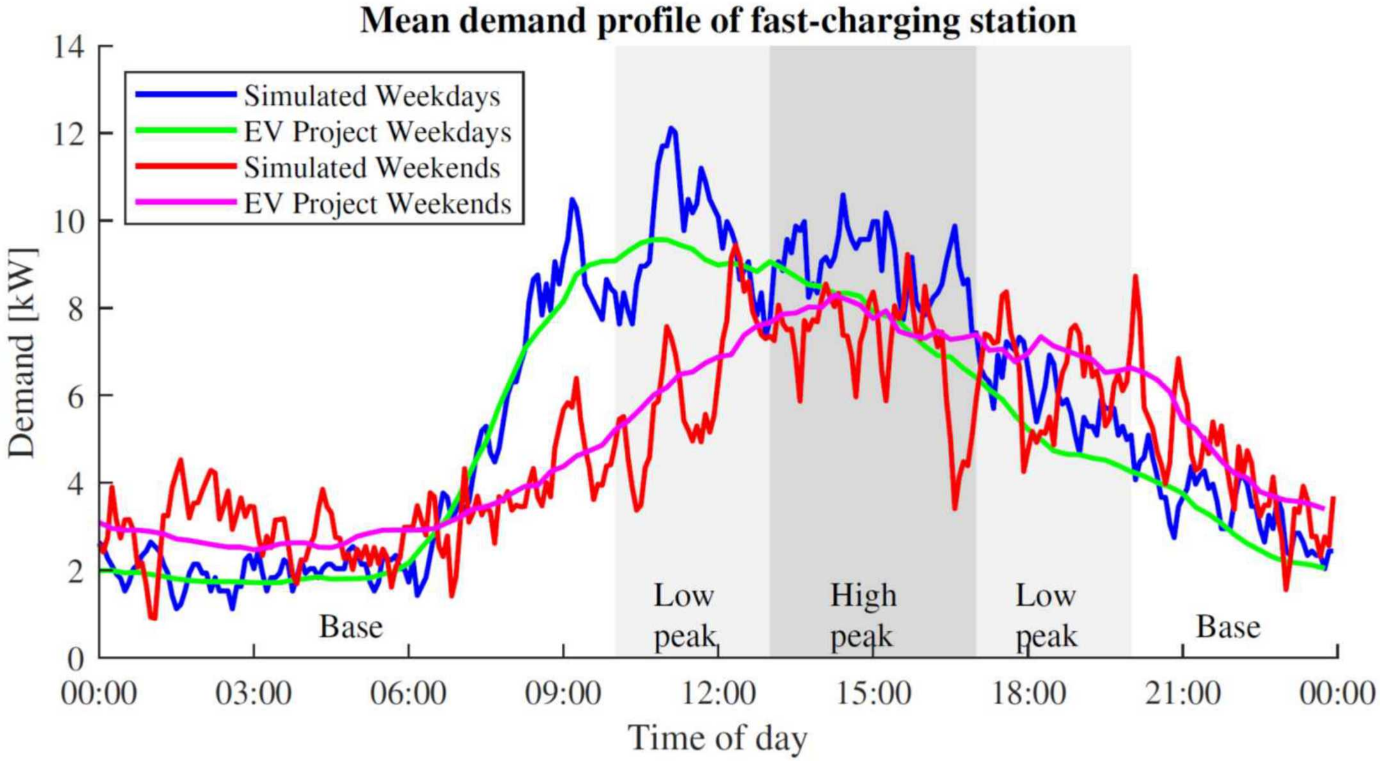
Load profiles

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



Load profiles

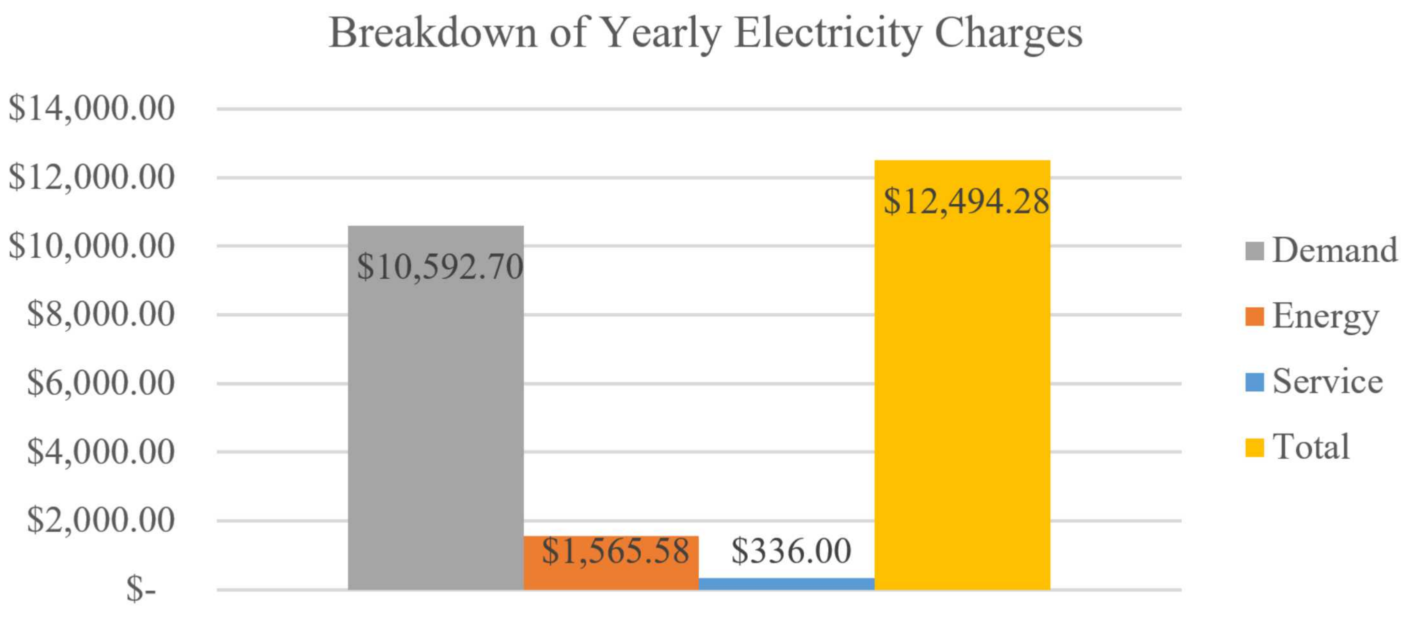
- Zero reactive power costs
- Data synthesized based on statistics of charging
- Distributions of time spent per charging session, energy used in each charging session



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

Solution of the LP: 298 seconds (GLPK solver)

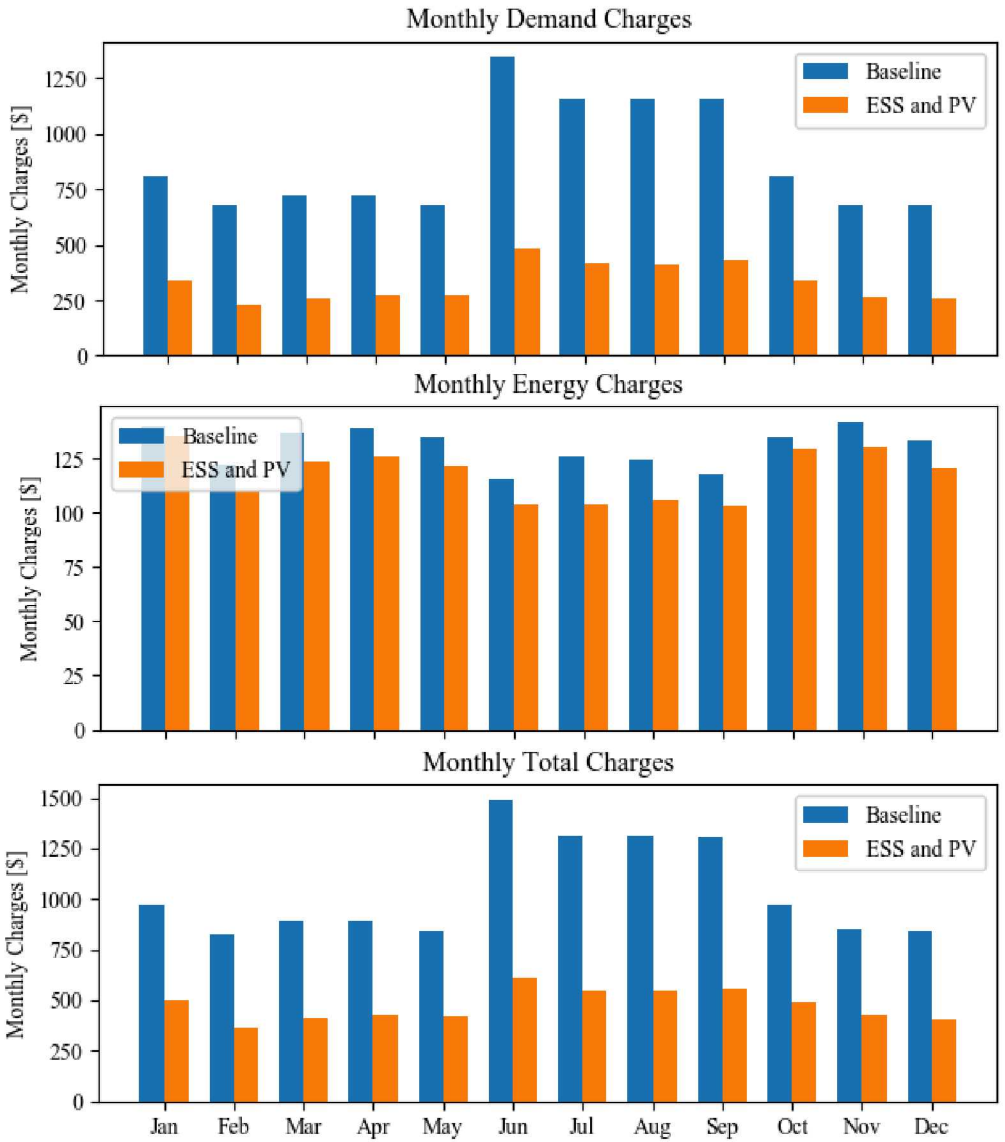
Energy equivalent of 170 cycles/year

No PV!

SUMMARY OF OPTIMIZATION RESULTS

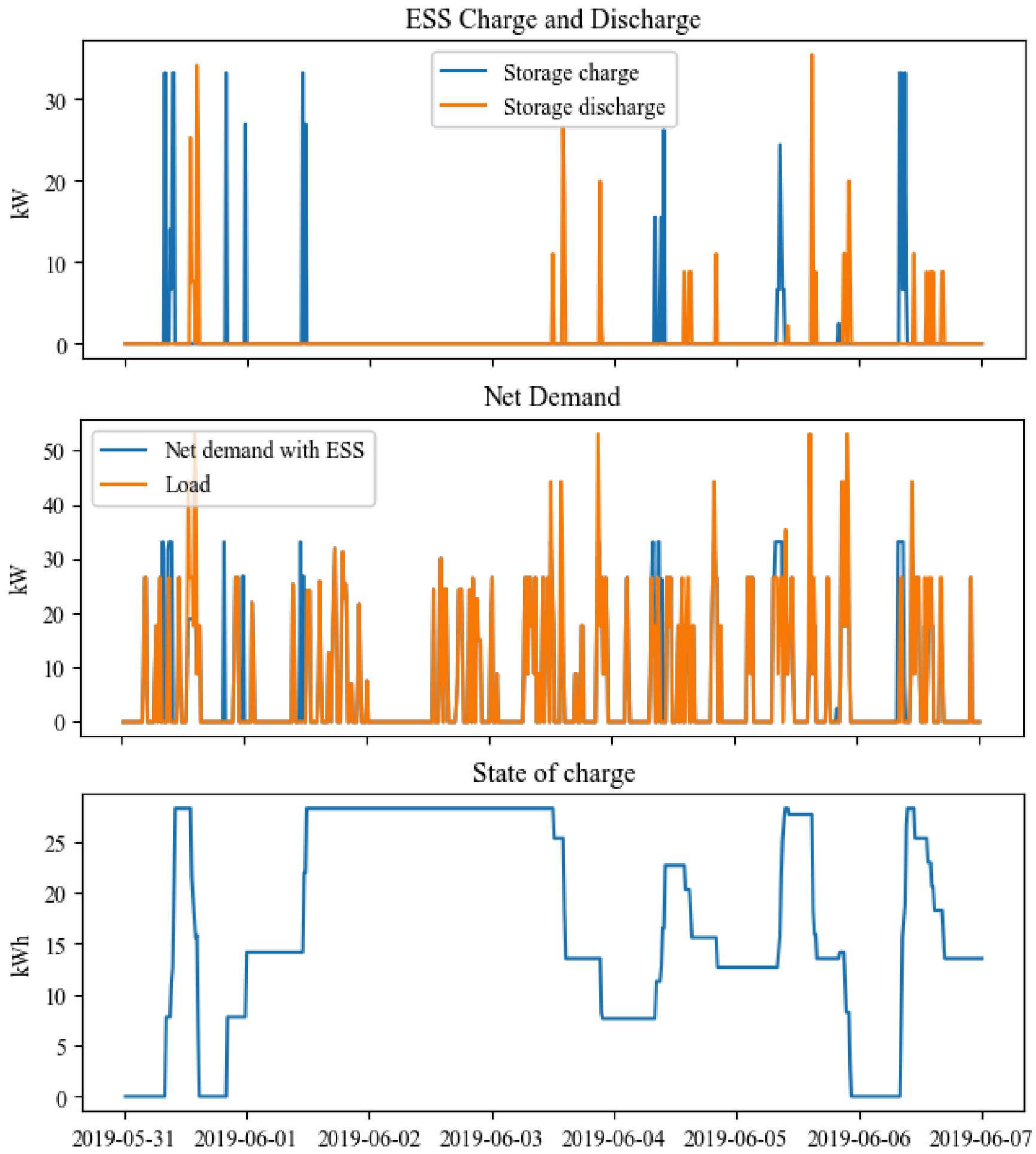
	Variable	**Value**	**Variable**	**Value**
	PV cost	\$0.00	ESS cost	\$28551
	ROI	\$22374.50	n_y	10 yrs
	i_r	5%/yr	PV size	0.0kW
	ESS power	46.49 kW	ESS energy	28.26kWh
Base	Max demand	79.70kW	Energy	46.7MWh/yr
	Demand cost	\$10592.70/yr	Energy cost	\$1565.58/yr
	Service	\$336.0/yr	Total cost	\$12494.28/yr
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



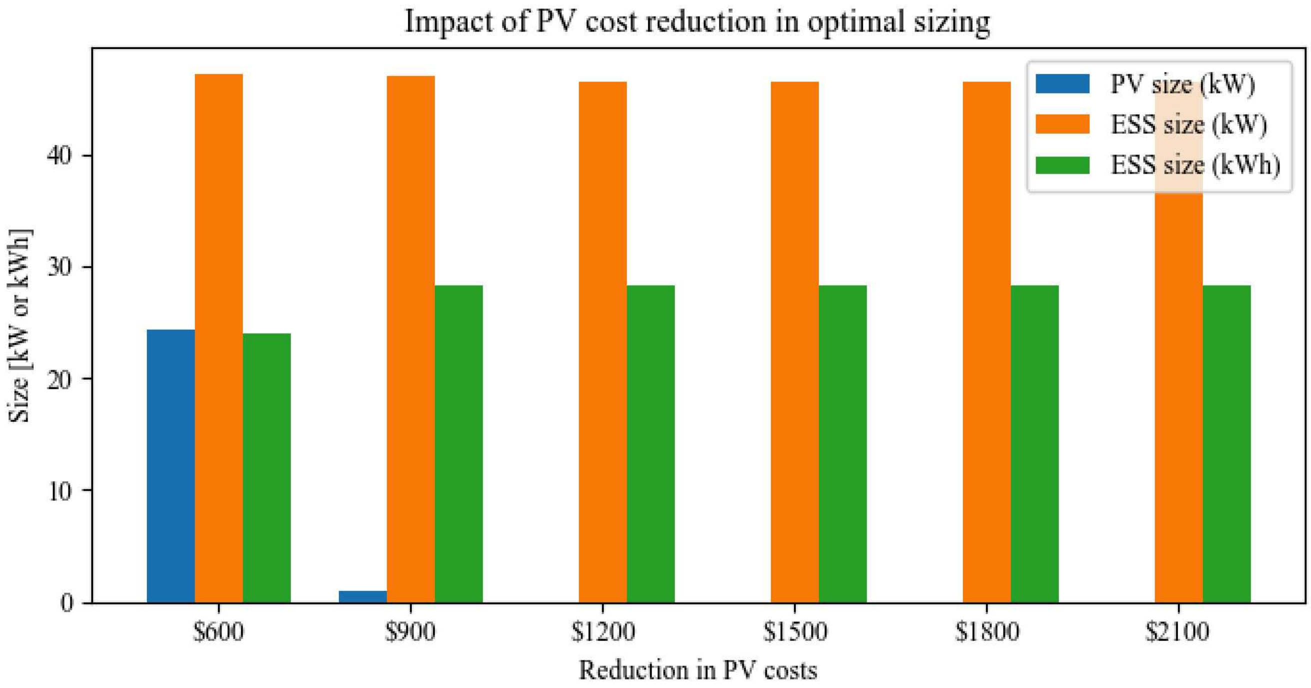
Monthly Demand Charges
Monthly Charges [$]
1250
1000
750
500
250
0
Baseline
ESS and PV
Monthly Energy Charges
Monthly Charges [$]
125
100
75
50
25
0
Baseline
ESS and PV
Monthly Total Charges
Monthly Charges [$]
1500
1250
1000
750
500
250
0
Baseline
ESS and PV
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov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

Results



ESS Charge and Discharge
Storage charge
Storage discharge
kW
30
20
10
0
Net Demand
Net demand with ESS
Load
kW
50
40
30
20
10
0
State of charge
kWh
25
20
15
10
5
0
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

R. D. Trevizan, T. A. Nguyen and R. H. Byrne, "Sizing Behind-the-Meter Energy Storage and Solar for Electric Vehicle Fast-Charging Stations," 2020 International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM), Sorrento, Italy, 2020, pp. 583-588, doi: 10.1109/SPEEDAM48782.2020.9161848.

Acknowledgment

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Thank you!

Q&A?