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Sizing Energy Storage System for Energy Arbitrage in Extreme Fast Charging Station

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Background

- Integration of ESS with extreme fast charging station (XFCS)
  - Power buffering: mitigate power swings and subsequent voltage transients caused by the extreme fast charging of EVs in the host distribution network
  - Energy buffering: decrease the operational cost of charging stations by exploiting the energy arbitrage opportunities
- Optimal sizing of ESS & energy management of the XFCS is a critical step for minimization of investment and operation costs while satisfying XFCS's performance requirements and ESS life degradation considerations.
- A novel non-linear programming (NLP) model to optimally size the energy storage system (ESS) and obtain an optimal energy management for energy arbitrage of an XFCS

Background - 2

- Highlights:
  - ✓ ESS optimal energy and power ratings
  - ✓ Optimal energy management of the studied XFCS
  - ✓ Reduction of total demand charges
  - ✓ Improved ESS life degradation (optimal DoD and annual cycles) modeling based on polynomial curve fitting
  - ✓ ESS cycle counting based on cumulative charge/discharge energy
  - ✓ Decision vector $\mathcal{V} = [C_{ESS}, P_{ESS}^{rated}, DoD, ESS\ cycles, E_{ESS}(t), E_g^{AC}(t), \mathrm{P_{g,mon}^{max}}, \mathrm{P_{g,ann}^{max}}]$.
- Objective Function:

$$\min_{\mathcal{V}}.\Bigg(\mathrm{SF^M} \times \overbrace{\left(\mathrm{P_{g,mon}^{max}} \times \mathrm{\lambda_{MDC}}\right)}^{\text{Monthly demand charges (MDC)}} + \overbrace{\left(\mathrm{P_{g,ann}^{max}} \times \mathrm{\lambda_{ADC}}\right)}^{\text{Annual demand charges (ADC)}}$$
$$+ \overbrace{\left(\mathrm{C_{ESS}} \times (\mathrm{CE_{capital}} + \mathrm{C_{inst}}) + \mathrm{P_{ESS}^{rated}} \times (\mathrm{CP_{capital}} + \mathrm{C_{O\&M}})\right)}^{\text{Investment cost,installation cost,and O\&M cost of ESS}}$$
$$+ \overbrace{\mathrm{SF^D} \times \left(\mathrm{E'_g(t)} \times (\mathrm{\lambda_E(t)} + \$0.01)\right)}^{\text{Cost of energy exchanged with Grid}} \Bigg)$$

- Selected Constraints:

- $$E'_g(t) = \frac{1}{\eta_{AC-DC}} \times \frac{1}{\eta_{DC-DC}} \times \left(\frac{2}{7} \times E_{NWD}(t) + \frac{5}{7} \times E_{WD}(t) + E_{ESS}(t)\right),\ \forall t \in T \quad (1)$$

- $$\left.\begin{array}{c} P'_{g,avg}(k) = \frac{1}{\xi} \times \sum_{t=1+\xi\times(k-1)}^{k\times\xi} \left(\frac{E'_g(t)}{\Delta t}\right) \\ P_{g,ann}^{max} = P_{g,mon}^{max} = P_{g,daily}^{max} = \max\left(P'_{g,avg}(k)\right) \end{array}\right\},\ \forall k \quad (2)$$

- $$\psi = \frac{365}{(C_{ESS})} \times \sum_{t\in T} \left(\frac{E_d(t)}{\eta_{disch}}\right) = \frac{365}{(C_{ESS})} \times \sum_{t\in T} (E_{ch}(t) \times \eta_{ch}),\ \forall t \in T \quad (3)$$

- $$\left.\begin{array}{c} \Gamma(DoD, LT) = 56603.45 - 1791.35 \times \mathrm{DoD} + 21.47 \times \mathrm{DoD}^2 - 0.09 \times \mathrm{DoD}^3 \\ \psi \leq \Gamma(DoD, LT) \end{array}\right\} \quad (4)$$

Results: Optimal Energy Management of the XFCS

- Optimal ESS ratings are 672 kW/2795 kWh.
- Optimal ESS DoD/annual cycles are 91.9%/346.
- Without degradation considerations, ESS will reach its End-of-Life (EOL) after ~7 years and will need to be replaced, thus incurring extra cost.
- With ESS, the maximum average power imported from grid has reduced from 876 kW to 646 kW.

Fig. 1: Charging station energy demand and electricity market price

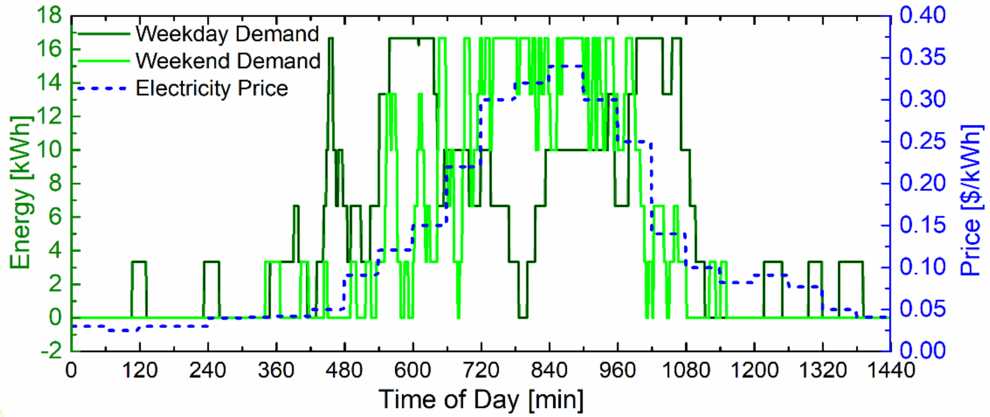


Fig. 2: Optimal energy management: energy from grid, ESS charging/ discharging energy, and SoC variations of the ESS

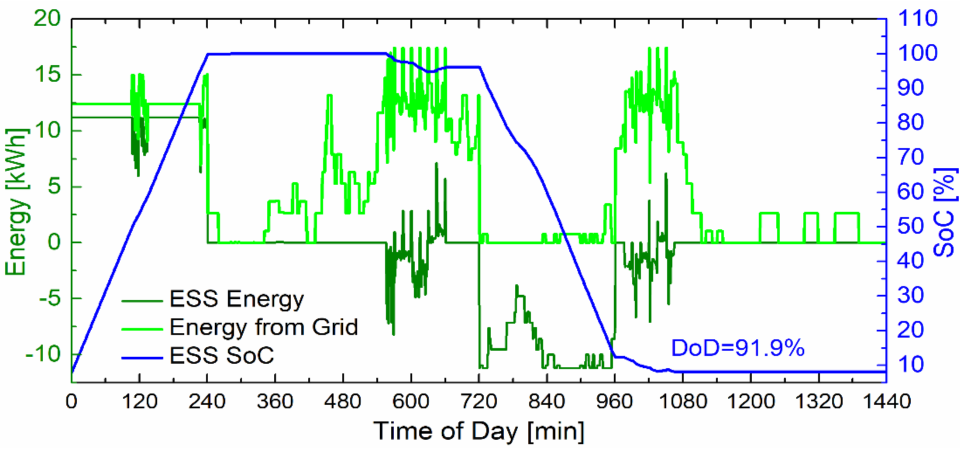
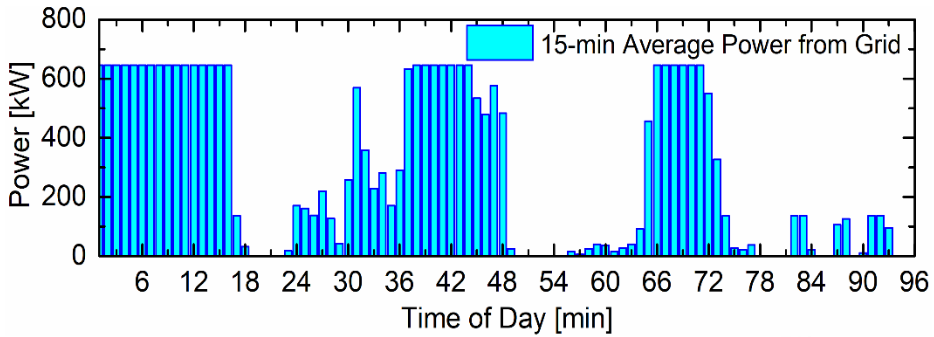


Fig. 3: Average power imported from the PDN



Results: Sensitivity Analysis with Allowed Cycles, Electricity Price, and ESS Investment Cost

Fig. 4: Sensitivity of ESS sizing and savings with allowed No. of ESS cycles

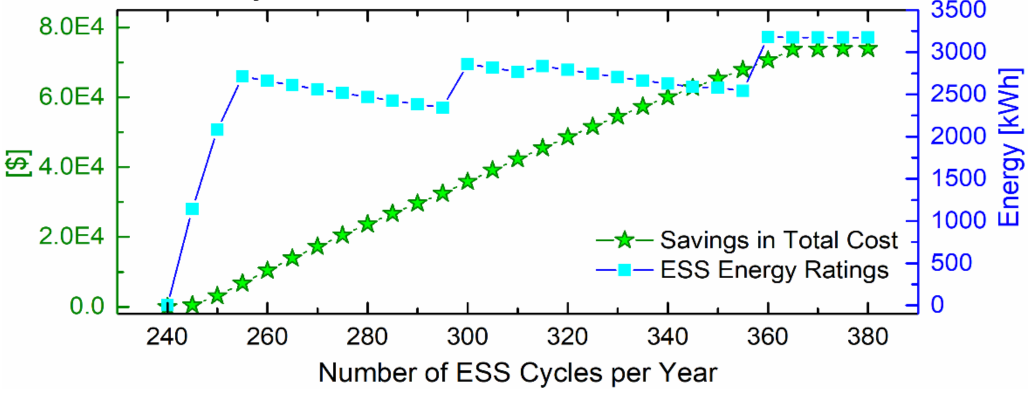


Fig. 6: Sensitivity of ESS sizing and savings with EIMF

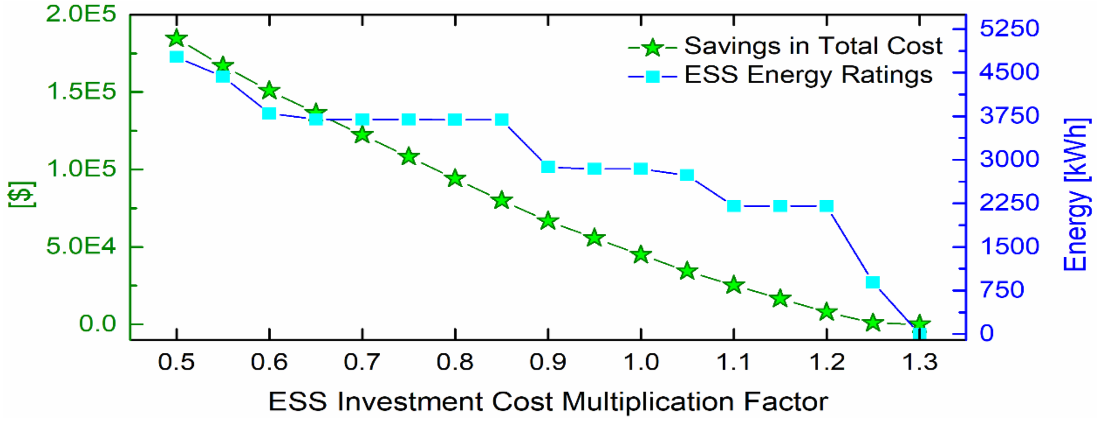


Fig. 5: Sensitivity of ESS sizing and savings with EPMF

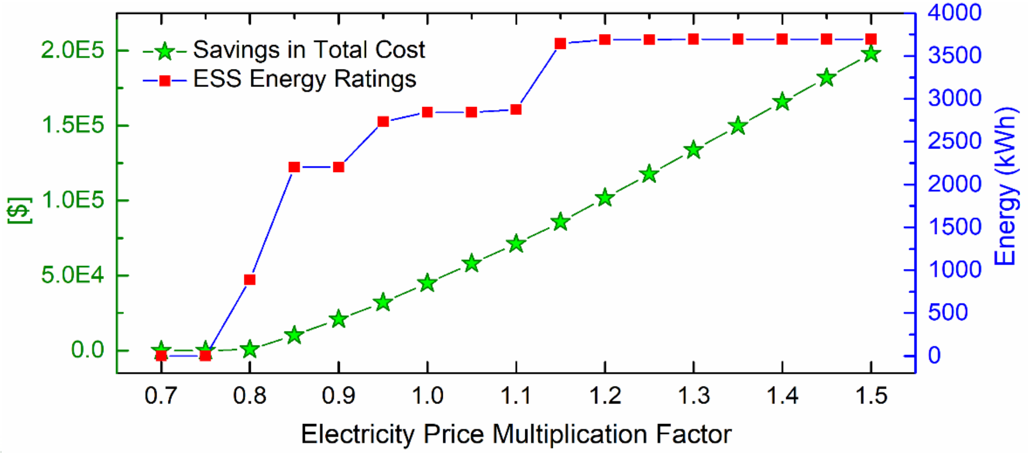
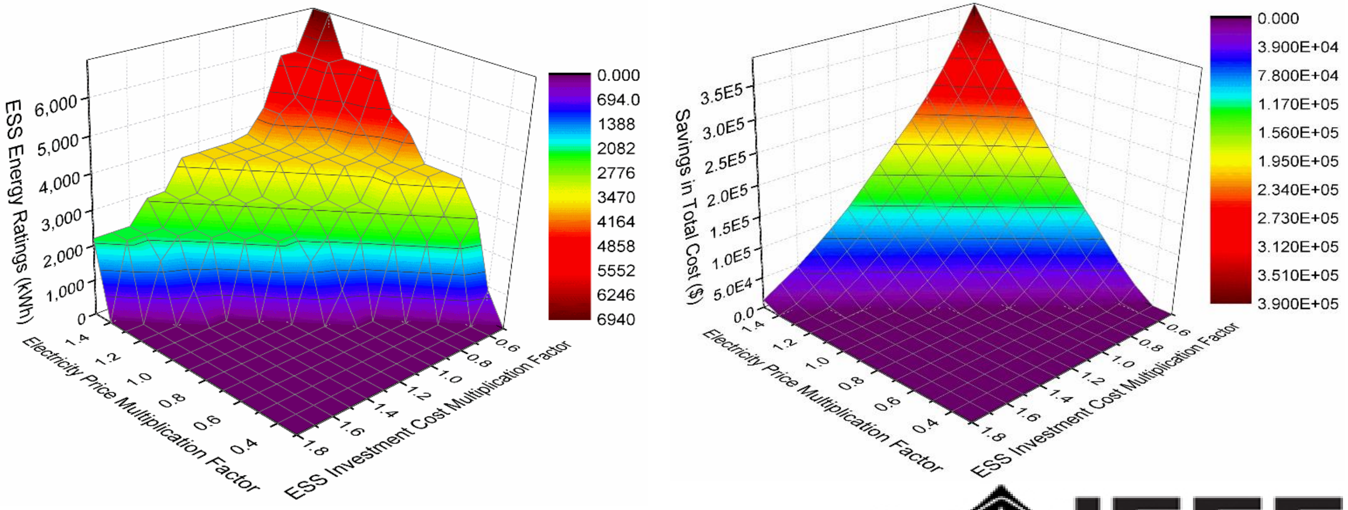


Fig. 7: Sensitivity of ESS sizing and savings jointly with EPMF and EIMF



Conclusions/Recommendations

- Inclusion of improved ESS life degradation modeling ensures that it will not reach to its EOL within the project lifetime.
- ESS helps lower the monthly and annual demand charges for the power imports from grid.
- Sensitivity analysis reveals that
  - ESS energy rating and total savings rise with increase in the difference between off-peak and peak period prices of the energy imported from the grid
  - Increase in ESS investment cost lowers energy rating of the ESS and total savings
- Future work:
  - Application of renewable resources
  - Uncertainty modeling in the input data (charging demand, electricity prices)
  - Linearization of the NLP model