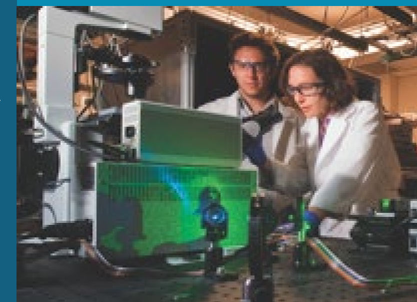
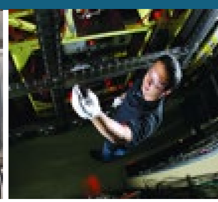
Optimal Time-of-Use Management with Power Factor Correction Using Behind-the-Meter Energy Storage Systems





PRESENTED BY

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Sandia National Laboratories

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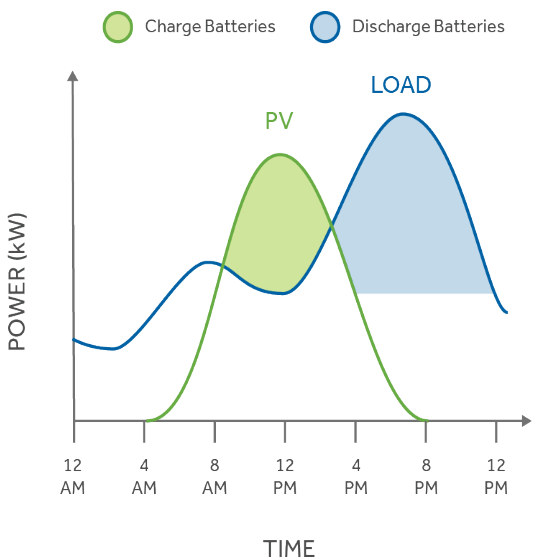
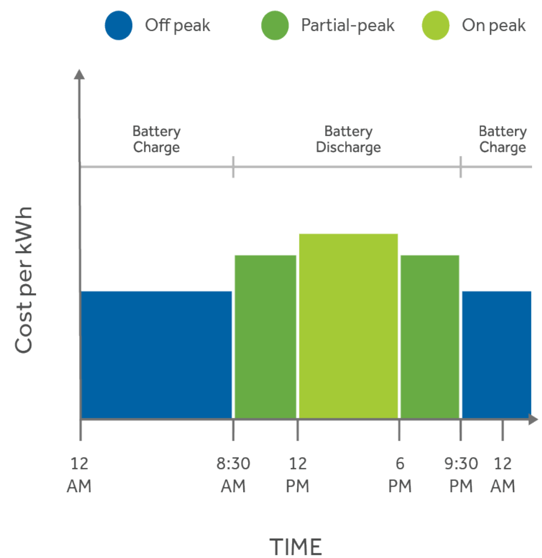
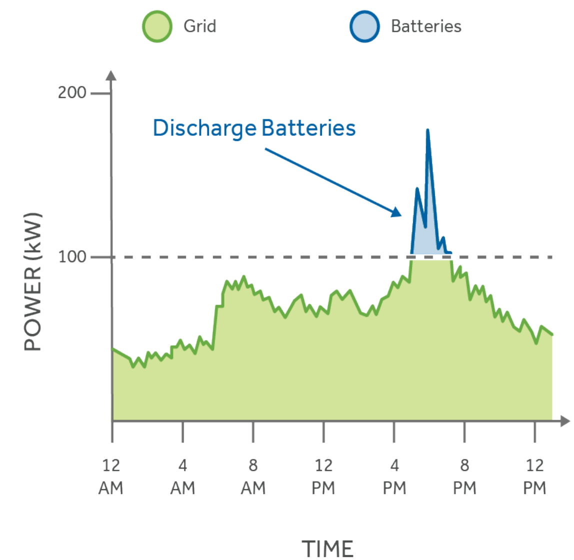
Behind-the-meter Applications



Renewable Time Shift



Time-of-use Management



Demand Charge Reduction

Image Credit - *Aquion Energy*

In this work, we propose an approach to maximize the economic benefit of BTM energy storage for TOU management while providing power factor correction.

This approach is best suited for large commercial or industrial customers who are often billed for their high peak demand and penalized for their low power factors.

Methodology

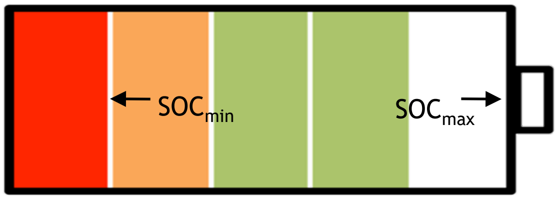
In the proposed approach, an MIP problem is formulated to find the optimal charge/discharge powers that minimize the monthly electricity bills while correcting the power factor of the customers.

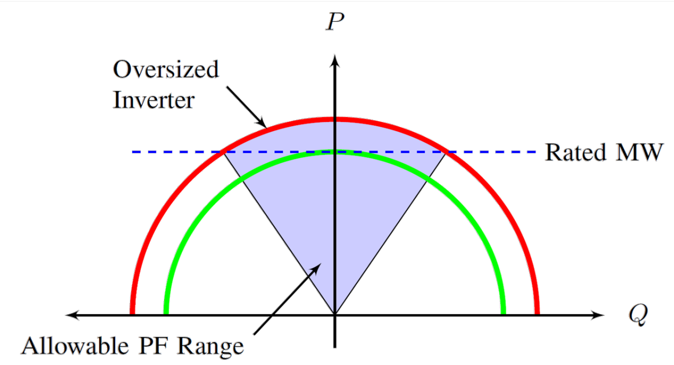
The constraints of this problem include:

- **Energy storage constraints:** state of charge constraints.
- **Inverter constraints:** charge/discharge power constraint, inverter's reactive power constraint, output power factor constraint.

The problem is then transformed to a Linear Programming (LP) problem using a Minmax technique.

Image Credit - *Energy Sage*





Formulation

Objective Function:

$$\min\{\mathrm{k_{pf}}(\mathrm{C_E^m} + \mathrm{C_D^m}) + \mathrm{C_N^m}\}$$

$$\mathrm{C_E^m} = \tau \sum_{i \in \mathrm{H^m}} \alpha_i P_i^{\mathrm{net}} \mathrm{pr}_i \quad \mathrm{C_N^m} = \tau \sum_{i \in \mathrm{H^m}} (1-\alpha_i) P_i^{\mathrm{net}} \mathrm{pr}_i^{\mathrm{s}}$$

$$\mathrm{C_D^m} = \max_{i \in \mathrm{H^m}} \{P_i^{\mathrm{net}}\} \mathrm{d_{max}^m} + \max_{j \in \mathrm{H_{pk}^m}} \{P_j^{\mathrm{net}}\} \mathrm{d_{pk}^m} + \max_{k \in \mathrm{H_{ppk}^m}} \{P_k^{\mathrm{net}}\} \mathrm{d_{ppk}^m}$$

Minimax Technique:

$$\alpha_i = \begin{cases} 1 & \text{if } P_i^{\mathrm{net}} \geq 0 \\ 0 & \text{otherwise} \end{cases} \Leftrightarrow \begin{cases} \alpha_i P_i^{\mathrm{net}} = \max\{P_i^{\mathrm{net}}, 0\} \\ (1-\alpha_i) P_i^{\mathrm{net}} = P_i^{\mathrm{net}} - \max\{P_i^{\mathrm{net}}, 0\} \end{cases}$$

Storage Constraints:

$$S_i = \gamma_{\mathrm{s}} S_{i-1} + \gamma_{\mathrm{c}}(P_i^{\mathrm{c}} - P_i^{\mathrm{lc}})\tau - (P_i^{\mathrm{d}} + P_i^{\mathrm{ld}})\tau/\gamma_{\mathrm{d}}$$

$$0 \leq S_i \leq \overline{S} \quad \tau \sum_{i \in \mathrm{H}} \left(\gamma_{\mathrm{c}}(P_i^{\mathrm{c}} - P_i^{\mathrm{lc}}) - (P_i^{\mathrm{d}} + P_i^{\mathrm{ld}})/\gamma_{\mathrm{d}}\right) = 0$$

Inverter Constraints:

$$\begin{aligned} 0 &\leq Q_i^{\mathrm{c}} \leq \tan\overline{\Phi} P_i^{\mathrm{c}} \\ 0 &\leq Q_i^{\mathrm{d}} \leq \tan\overline{\Phi} P_i^{\mathrm{d}} \\ (P_i^{\mathrm{c}})^2 &+ (Q_i^{\mathrm{c}})^2 \leq (\overline{P})^2 \\ (P_i^{\mathrm{d}})^2 &+ (Q_i^{\mathrm{d}})^2 \leq (\overline{P})^2 \end{aligned} \xrightarrow{\textit{Linearize}} \begin{aligned} a_1 Q_i^{\mathrm{c}} + b_1 P_i^{\mathrm{c}} &\leq c_1 \overline{P} \\ a_2 Q_i^{\mathrm{c}} + b_2 P_i^{\mathrm{c}} &\leq c_2 \overline{P} \\ a_1 Q_i^{\mathrm{d}} + b_1 P_i^{\mathrm{d}} &\leq c_1 \overline{P} \\ a_2 Q_i^{\mathrm{d}} + b_2 P_i^{\mathrm{d}} &\leq c_2 \overline{P} \end{aligned}$$

Case Studies

- An industrial customer in New Mexico is considered: a water treatment facility (300kW peak load) with 100kW PV.
- Fixed energy rate and TOU demand rate are applied.
- Penalty is applied for power factor lower than 0.9

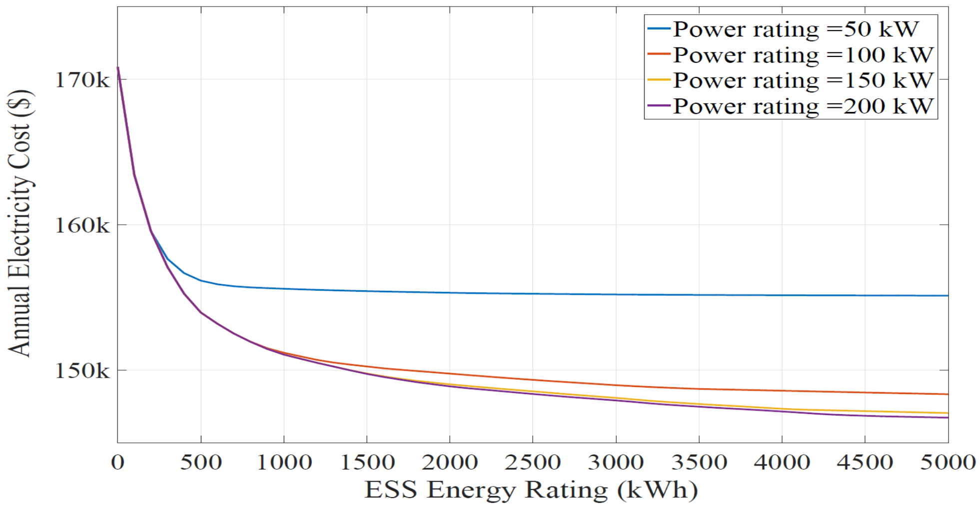
Energy rate: $\mathrm{pr} = 0.04537\ [\$/kWh]$
Peak-hour (6am-9pm) demand rate: $\mathrm{d_{pk}} = 24.69\ [\$/kW]$
Off-peak (9pm-6am) demand rate: $\mathrm{d_{opk}} = 6.12\ [\$/kW]$
Net-metering rate: $\mathrm{pr_s} = 0.03[\$/kWh]$

Image Credit – *New Mexico Environment Department*

Case 1: TOU management without power factor correction

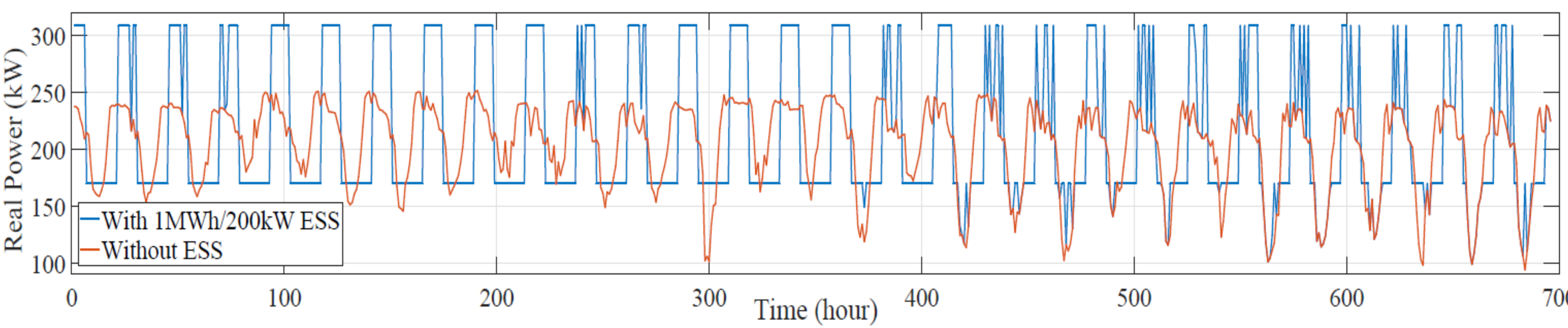
Case 2: TOU management with power factor correction

Case I - TOU management without power factor correction



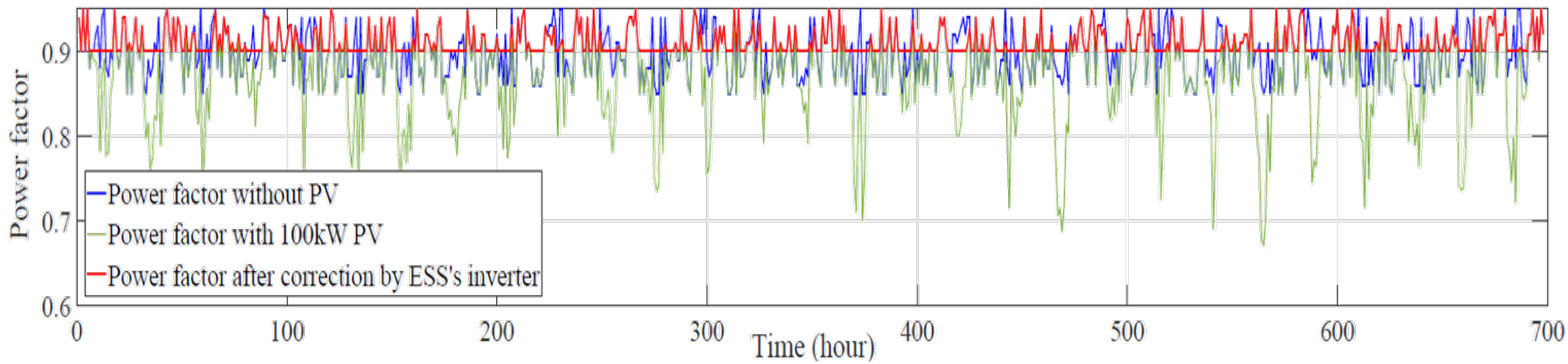
Sensitivity of cost to ESS's size

- Optimal size: 200kW/1MWh.
- Total saving: $30k (16.8%)
- Peak demands have been shifted to off peak hours.

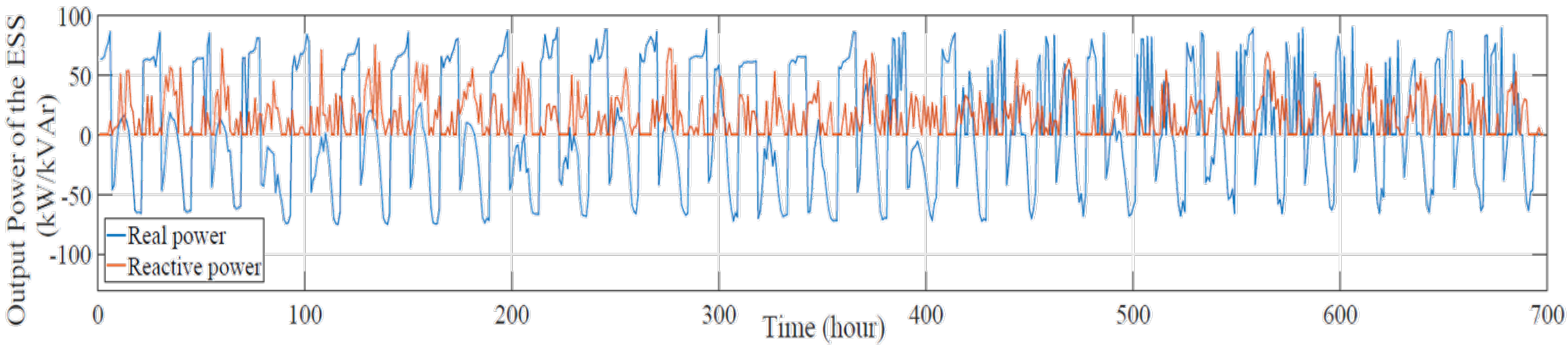


Net load during Feb 2016

Case II - TOU management with power factor correction



Power factor profile in Feb 2016 assuming 200kW/1MWh ESS



Real and reactive power profile in Feb 2016 assuming 200kW/1MWh ESS

Conclusions

- In this work, the benefits of behind-the-meter ESSs for TOU management with power factor correction have been studied.

- Specifically, the main contributions of this paper include:
  - A formulation of the optimal TOU management combined with power factor correction for BTM energy storage that consider inverter's reactive power capability.
  - A Minmax-based technique for transforming the energy storage MINLP problem to a LP problem.

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