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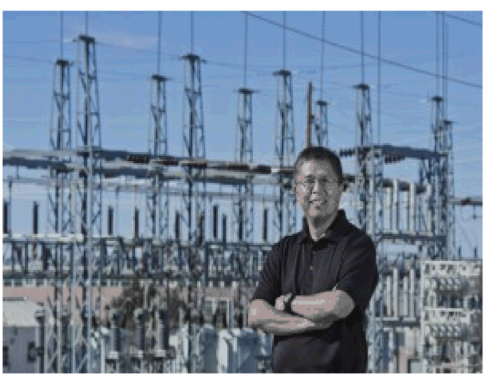

Maximizing Revenue from Electrical Energy Storage in MISO Energy & Frequency Regulation Markets

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Abstract

This paper presents the calculations to maximize the potential revenue of electrical energy storage (EES) from participation in arbitrage and frequency regulation in MISO using linear programming.

MISO Performance Tests

- Instructed mileage

$$q_i^{\mathrm{insM}} = \sum_{k=1}^{N} |s_k - s_{k-1}|$$

- Actual mileage

$$q_i^{\mathrm{actM}} = \sum_{k=1}^{N} (|s_{k-1} - q_{k-1}| - |s_{k-1} - q_k|)$$

- Desired mileage

$$q_i^{\mathrm{desM}} = \sum_{k=1}^{N} |d_k - d_{k-1}|$$

- 5min performance test

$$\eta_i = \frac{q_i^{\mathrm{actM}}}{q_i^{\mathrm{desM}}} \begin{cases} \geq 0.7 & \text{Pass} \\ < 0.7 & \text{Fail} \end{cases}$$

- Target mileage

$$q_i^{\mathrm{tagM}} = \min\{q_i^{\mathrm{insM}}, q_i^{\mathrm{desM}}\}$$

- Hour performance test

$$\eta_t = \begin{cases} 0 \text{ (Fail)} & \eta_i < 0.7 \text{ for 4 cons. int} \\ 1 \text{ (Pass)} & \text{otherwise} \end{cases}$$

MISO Performance-based Compensation

- Pre-payment $q_t^{\mathrm{REG}} \mathrm{MCP}_t^{\mathrm{REG}}$ [$]
- Payment for additional mileage

$$A_t^i = \begin{cases} \left(q_i^{\mathrm{tagM}} - \frac{\alpha}{12} q_t^{\mathrm{REG}}\right) \mathrm{MCP}_t^{\mathrm{MIL}} & \text{if } \eta_i \geq 0.7 \\ \eta_i \left(q_i^{\mathrm{tagM}} - \frac{\alpha}{12} q_t^{\mathrm{REG}}\right) \mathrm{MCP}_t^{\mathrm{MIL}} & \text{if } \eta_i < 0.7 \end{cases}$$

- Charge for undeployed mileage

$$U_t^i = \left(\frac{\alpha}{12} q_t^{\mathrm{REG}} - q_i^{\mathrm{tagM}}\right) \mathrm{MCP}_t^{\mathrm{MIL}}$$

- Total payment

$$R_t^{\Sigma} = \eta_t \left[q_t^{\mathrm{REG}} \mathrm{MCP}_t^{\mathrm{REG}} + \sum_{i=1}^{M} (A_t^i - U_t^i + W_t^i)\right]$$

Energy Storage State of Charge

- For arbitrage

$$S_t = \gamma_s S_{t-1} + \gamma_c q_t^{\mathrm{R}} - q_t^{\mathrm{D}} \ \forall t \in T$$

- For arbitrage and regulation

$$S_t = \gamma_s S_{t-1} + \gamma_c q_t^{\mathrm{R}} - q_t^{\mathrm{D}} + \gamma_c \gamma_t^{\mathrm{RD}} q_t^{\mathrm{REG}} - \gamma_t^{\mathrm{RU}} q_t^{\mathrm{REG}}, \ \forall t \in T$$

Problem Formulation

- For arbitrage

$$\mathrm{Max} \sum_{t=1}^{T} \left[(\mathrm{P}_t - \mathrm{C_d})\, q_t^{\mathrm{D}} - (\mathrm{P}_t + \mathrm{C_r})\, q_t^{\mathrm{R}}\right] e^{-rt}$$

$s.t.$ energy storage constraints.

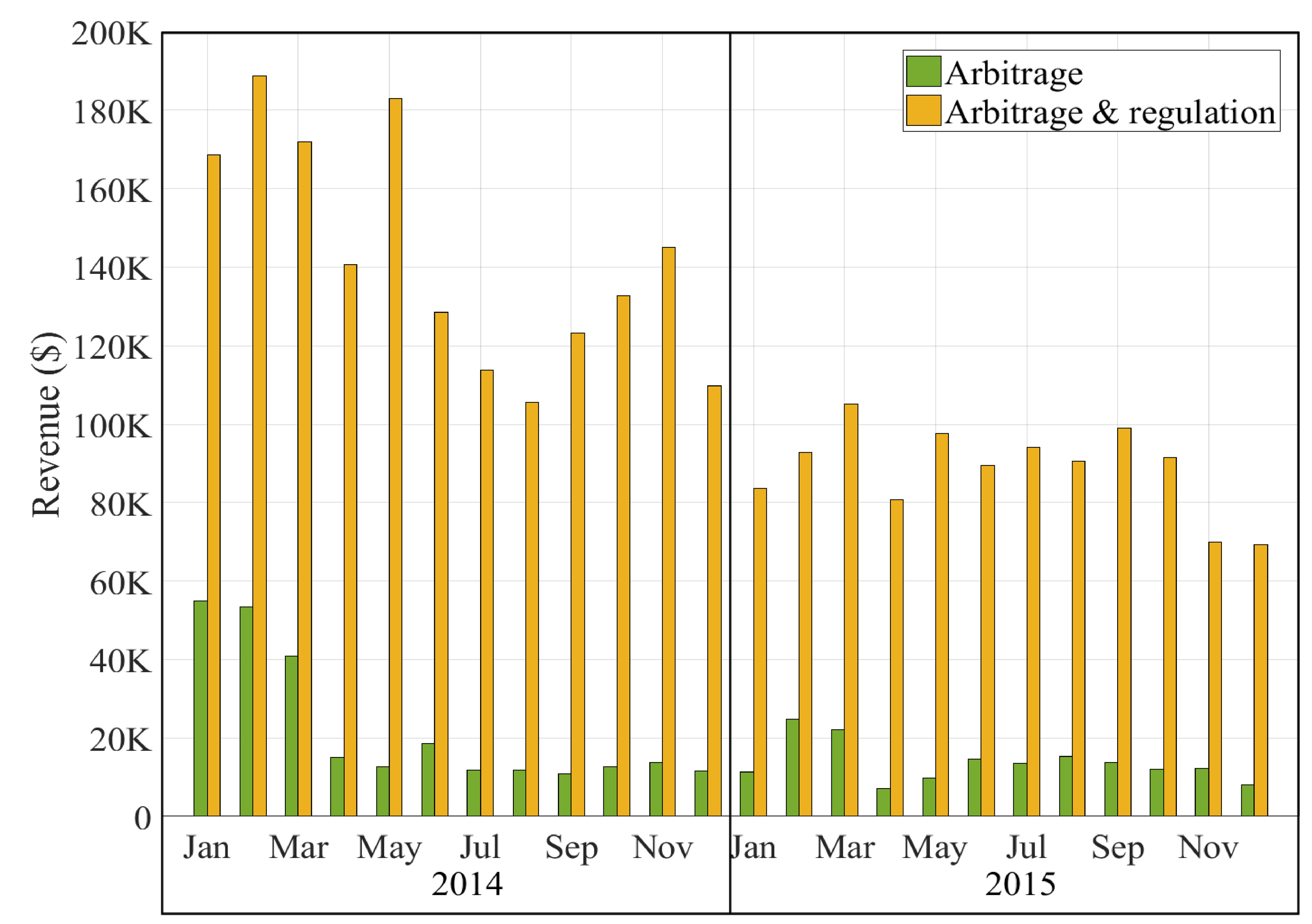
- For frequency regulation

$$\mathrm{Max} \sum_{t=1}^{T} \left[(\mathrm{P}_t - \mathrm{C_d})\, q_t^{\mathrm{D}} - (\mathrm{P}_t + \mathrm{C_r})\, q_t^{\mathrm{R}} + 0.95 \times 1.03 q_t^{\mathrm{REG}} \mathrm{MCP}_t^{\mathrm{REG}}\right] e^{-rt}$$

$s.t.$ energy storage constraints.

Results

- Case study: 20MW/MWh BESS at Harding Street Generation Station of Indianapolis Power & Light.



- The revenue from arbitrage combined with regulation is much higher than from arbitrage only.
- The optimal policy is to participate in regulation market the majority of the time while maintaining the SOC by arbitrage.

Conclusions

- An LP approach has been used to estimate the revenues of an EES system in MISO for arbitrage only and arbitrage combined with frequency regulation.
- Future work would consider the uncertainties of the forecast data and non-linear energy storage model.

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