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Maximizing Revenue from Electrical Energy Storage in the Electricity Reliability Council of Texas (ERCOT)

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RESEARCH GOALS

- Quantify the revenue of a notional energy storage system located in ERCOT.
- Identify the optimal mix of arbitrage and frequency regulation to maximize revenue.

ELECTRICITY STORAGE MODEL

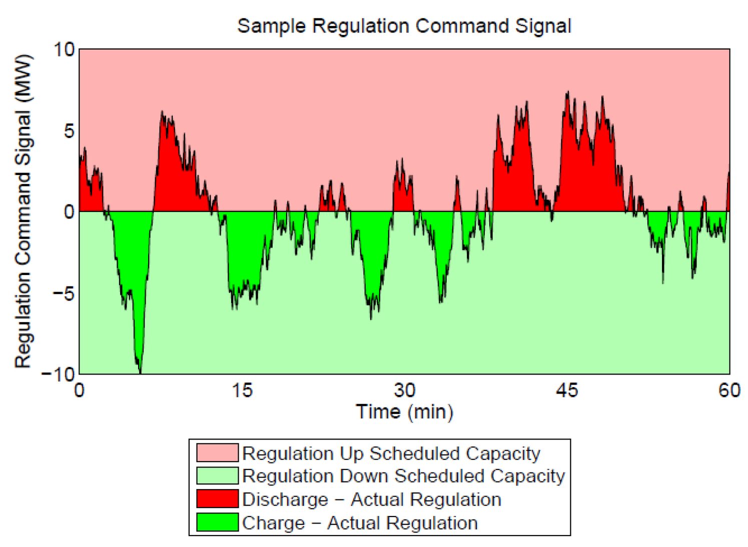
For a storage device that provides only one service there are two decision variables in the optimization: the energy sold q_t^D (discharged) at time t, and the energy purchased q_t^R (recharged) at time t in MWh. They are assumed to be nonnegative quantities. In this case, the state of charge (SOC) S_t at any time t is given by:

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

which states that the SOC at time t is the SOC at time $t-1$ adjusted for storage losses, γ_s , plus any net charging (adjusted for conversion losses, γ_c) minus the quantity discharged during t. Additional constraints include:

$$\begin{aligned} 0 \leq & S_t \leq \bar{S}, \ \forall t \in T \\ 0 \leq & q_t^R \leq \bar{q}^R, \ \forall t \in T \\ 0 \leq & q_t^D \leq \bar{q}^D, \ \forall t \in T \end{aligned}$$

For a device that is participating in arbitrage and the regulation market, a few additional parameters must be added into the storage device model. Additional decision variables to handle separate RegUp and RegDown markets are: the energy offered into the RegUp market q_t^{RU} at time t, and the energy offered into the RegDown market q_t^{RD} at time t in MWh. These decision variables are assumed to be non-negative quantities. In regulation markets, there is no guarantee that the capacity reserved will actually be deployed. A representative regulation command signal is shown below.



In order to quantify the change in SOC from participation in the regulation market, it is useful to define the RegUp efficiency γ_{ru} as the fraction of the RegUp reserve capacity that is actually deployed in real-time (on average). Similarly, the RegDown efficiency γ_{rd} is the fraction of the RegDown reserve capacity that is actually deployed in real-time (on average). For the figure above, the RegUp/RegDown efficiency is approximately 13%. Another assumption is that the regulation signal is allocated equally among participating regulation resources, e.g. over any given time period the regulation signal for each resource is proportional to the total regulation need. The scale factor is the quantity offer by that resource divided by the total quantity procured. Thus, the SOC at time t for a device participating in arbitrage and regulation is given by:

$$S_t = \gamma_s S_{t-1} + \gamma_c q_t^R - q_t^D + \gamma_c \gamma_{rd} q_t^{RD} - \gamma_{ru} q_t^{RU}$$

And it is complemented by the following constraints:

$$\begin{aligned} 0 \leq & S_t \leq \bar{S}, \ \forall t \in T \\ 0 \leq & q_t^R + q_t^{RD} \leq \bar{q}^R, \ \forall t \in T \\ 0 \leq & q_t^D + q_t^{RU} \leq \bar{q}^D, \ \forall t \in T \end{aligned}$$

MAXIMIZING STORAGE REVENUE

The problem of maximizing revenue from an energy storage device is naturally formulated as an LP optimization problem [6]. Next, the energy storage model presented above is combined with a cost function to maximize the revenue in two different scenarios: arbitrage and arbitrage combined with participation in the regulation market.

The objective function when the storage unit participates only in arbitrage is given by:

$$\max \sum_{t=1}^{T} \left[(P_t - C_d) q_t^D - (P_t + C_r) q_t^R \right] e^{-rt}$$

where P_t is the price of electricity (LMP) at time t in (\$/MWh), C_d is the cost of discharging at time t in (\$/MWh), C_r is the cost of recharging at time t in (\$/MWh) and r is the interest rate over one time period.

The objective function when the storage device participates in arbitrage and regulation is given by:

$$\begin{aligned} \max \sum_{t=1}^{T} [& (P_t - C_d) q_t^D + (P_t^{RU} + \gamma_{ru}(P_t - C_d)) q_t^{RU} + \\ & (P_t^{RD} - \gamma_{rd}(P_t + C_r)) q_t^{RD} - (P_t + C_r) q_t^R] e^{-rt} \end{aligned}$$

where P_t^{RU} t is the price of RegUp at time t and P_t^{RD} is the price of RegDown at time t. In many areas, the net energy for regulation is settled at the real-time price. This provides an additional arbitrage opportunity between the day ahead price and the real-time price. We assume that the price P_t represents both, the regulation and energy prices in the day ahead and do not take into account real-time revenue. While this does not reflect the actual settlement process, it keeps the optimization from incorporating any arbitrage between the day ahead and the real-time market.

RESULTS FOR ERCOT 2011/2012 MARKET DATA (HB_HOUSTON NODE)

The parameters for a notional energy storage system are listed below.

ENERGY STORAGE SYSTEM PARAMETERS.

Parameter	Value
$\bar{q}^D$	8 MWh
$\bar{q}^R$	8 MWh
$\bar{S}$	32 MWh
γ_S	1.0
γ_C	0.8
γ_{ru}	0.5
γ_{rd}	0.5

Using these values, and historical data from the ERCOT website, we obtained the following results:

ARBITRAGE OPTIMIZATION RESULTS USING PERFECT KNOWLEDGE, 2011-2012, ERCOT HB_HOUSTON NODE.

Year	Revenue	% Discharging	% Charging
2011	\$1,054,905.61	18.86%	23.57%
2012	\$375,841.62	17.95%	22.44%

ARBITRAGE AND REGULATION OPTIMIZATION RESULTS USING PERFECT KNOWLEDGE, 2011-2012, ERCOT HB_HOUSTON NODE.

Year	Revenue	% q^D	% q^R	% q^{RU}	% q^{RD}
2011	\$2,360,994.81	0.14%	0.81%	69.49%	85.84%
2012	\$928,265.14	0.10%	0.79%	63.90%	78.53%

ARBITRAGE STRATEGY BASED ON PREVIOUS DAY PRICES, 2011-2012, ERCOT HB_HOUSTON NODE.

Year	Revenue	% of Maximum
2011	\$1,010,082.08	95.75%
2012	\$362,244.88	96.38%

ARBITRAGE AND REGULATION STRATEGY BASED ON PREVIOUS DAY PRICES, 2011-2012, ERCOT HB_HOUSTON NODE.

Year	Revenue	% of Maximum
2011	\$2,023,828.56	85.72%
2012	\$830,319.64	89.45%

CONCLUSIONS

First, electricity prices in market areas can fluctuate from year to year, and this resulted in significantly reduced revenue in 2012 compared to 2011. Second, because of the diurnal fluctuations in electricity prices, relatively simple strategies can capture a significant portion of the maximum revenue calculated using perfect knowledge. Future research will look at the effect of location and the resulting price variability to identify the best (from a revenue perspective) locations for energy storage systems in ERCOT.

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