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The value of energy storage in South Korea's electricity market: A Hotelling approach ☆

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HIGHLIGHTS

- We evaluate lifetime economic potential for energy arbitrage in South Korea.
- We simulate lifetime energy flows and profits for small price-taking NaS and Li-ion batteries.
- We devise optimal battery operating strategy using Hotelling's depletion rule.
- Cumulative profits depend on intraday price differences and social discount rate.
- At current electricity prices, neither battery generates enough arbitrage revenue to offset capital costs.

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ABSTRACT

In this study we evaluate the economic potential for energy arbitrage by simulating operation and resulting profits of a small price-taking storage device in South Korea's electricity market. As demand for electricity continues to grow, maintaining a balanced power system at all times has become more challenging in Korea and other developed nations. Along with demand response programs and increased renewable energy utilization, energy storage devices may provide a viable way to contribute to diurnal peak demand shaving. In some parts of the U.S. storage arbitrage has proven to be profitable. Treating a battery's ability to charge and discharge as a scarce resource, we apply the Hotelling (1931) rule to determine a strategy for maximizing the value of the battery. Results show that present market conditions in South Korea do not provide sufficient economic incentives for energy arbitrage using sodium–sulfur (NaS) or lithium-ion (Li-ion) batteries, with the capital cost of the storage devices exceeding potential revenues.

1. Introduction

Phasing storage devices into existing electricity networks can potentially help to address the challenge of rising peak generation costs by making lower-cost power generated during off-peak times available to meet peak-time demand. However, storage remains a weak link in electricity markets, partly due to the high cost of storage devices. Empirical studies differ on the economic viability of storage. Some authors find that potential storage arbitrage profits are not always sufficient to offset the capital cost of the storage device [1–7], while other simulations demonstrate more promising results [2–9]. In this study we evaluate the economic viability of storage in the South Korean electricity market. Specifically, using hourly day-ahead system marginal electricity prices (SMPs) for the years 2009–2011, published by Korea Power Exchange (KPX), and a set of charging and discharging rules, we calculate potential lifetime profits resulting from arbitrage activities using a small battery in Korea's energy market.

South Korea faces many of the challenges common to developed-world electricity sectors, including fluctuating costs of input fuels, regulated retail rates, and a continually growing demand for electric power. A large-scale blackout that roiled Seoul on September 15, 2011 caused much concern among citizens about the resilience of the country's existing power infrastructure [10,11]. During the summer of 2013, the country faced another potential electricity supply crisis as operation of three nuclear power plants was suspended during unusually hot summer weather due to corruption-related safety concerns [12,13]. The government responded with a public commitment to strengthen the nation's electricity

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networks through a combination of more efficient management via the smart grid and complementary increases in utilization of renewable energy and demand response programs [14,15]. At this time, demand response consists mainly of periodic mandates for power use reduction from large commercial and industrial users. Although these two measures can provide an effective stopgap solution to peak demand reduction, alone they are unlikely to resolve concerns about reliability. In fact, both demand response and renewable generation bring additional uncertainty into the power market: uncertainty in compliance in case of DR, and uncertainty in supply availability (intermittency) in case of renewables.

Storage devices can in principle complement the use of demand response and renewable generation in achieving a more stable and secure supply. The needed infrastructure can potentially be provided through private entry by independent owners of small-scale storage devices as long as the current diurnal variation in generation costs is sufficiently high to generate profits from storage operation (via energy arbitrage). Such private storage devices can prove to be particularly valuable to power markets facing peak reliability challenges. In this study we set out to determine whether South Korea's power markets offer sufficient financial incentives in the energy market to induce private entry into storage operations.

The next section summarizes existing literature on the topic of storage value; Sections 3 and 4 detail our simulation approach for two alternative storage technologies, NaS and Li-ion batteries, describe all utilized assumptions about market conditions and technological parameters, and present our findings. In particular, we present a strategy for maximizing a battery's charge and discharge capacity, following the classic Hotelling rule [16]. Section 5 concludes with a summary of main results for both technologies and a discussion of policy implications.

2. Literature review

Empirical studies on the economic viability of storage are largely dependent on the economic and technological circumstances surrounding any given storage project. All studies reviewed for this article point out that a storage device's ultimate profitability is a function of chosen storage technologies and their specifications, the level of regional electricity prices, prices of generation fuels, the particular market selected for storage operation (e.g. energy, regulation, ancillary), the quality of price forecasts, existence of government subsidies and their levels, and so on, and that all of these factors tend to vary over time, making accurate profitability analysis rather challenging.

For example, Ekman and Jensen [1] find that profits generated from energy arbitrage on Denmark's spot power markets were quite a bit lower than the capital costs of installing storage devices, rendering storage uneconomic. Similar financial results are obtained by [3–7]. Mulder et al. [3], studying solar energy systems in Western Europe find that it is not economic, without increases in electricity prices, to use batteries to support household photovoltaic installations. Similarly, in a 2007 paper analyzing regional New York grids, Walawalkar et al. [2] concluded that running peaking generators is generally more economic than using storage, given the economic and technological conditions surrounding markets under their evaluation. The authors also find, however, that storage operators in New York City had a high probability of earning positive profits from energy arbitrage and regulation activities using sodium–sulfur (NaS) and flywheel storage devices. The opportunities for positive economic returns in eastern and western parts of upstate New York, however, were much lower.

A thorough review of storage literature by Aucker et al. [6] points out that most studies of storage economics conclude that energy arbitrage by itself is not a profitable activity. A study of seven real-time U.S. electricity markets and 14 different storage technologies by Bradbury et al. [17] found that the optimal profit maximizing size of a storage device depends largely on its technological characteristics, rather than the magnitude of market price volatility. He and Zachmann [18] note that since power prices tend to stay low for longer duration of time than they remain high, the most profitable storage devices will be those that have low charging rates and high discharging rates, enabling them to take advantage of short peak pricing intervals.

On an larger scale, studies of pumped hydro and compressed energy storage systems to supply peak demand or support renewable integration [4,5], [9], and [19] find that such systems are not likely to be effective without appropriate government subsidies (e.g. feed-in tariffs) [4,5,19] or sophisticated high-frequency reserve markets in which generators can take advantage of real time price differences by trading hourly contracts [5]. In only one of our reviewed studies (that of a wind farm in southeastern Australia [9]) do the authors found positive rates of return to complementing the wind farm with pumped hydro, compressed air, or thermal energy storage systems. Generally, although the social or system benefits of storage integration can be high [20], lack of financial incentives prevents capital from seeking out storage projects.

Incorporating storage systems in South Korea's power industry is one component of the government's green growth strategy [21,22], which focuses on renewable energy and smart grid development. With several South Korean companies, including Samsung and LG Chem, having recently emerged as leading energy storage manufacturers, the country appears to be a good candidate for government-driven storage investment initiatives. However, private entry does not require large-scale coordination of resources and likely allows for faster implementation and a more flexible adjustment toward efficient storage capacity levels as market conditions change and technology evolves. In August 2013, the South Korean government announced plans to promote energy storage devices by encouraging their use by large enterprises and providing financial subsidies to small and medium-sized companies investing in storage systems, along with revising the electricity rate structure to further discourage peak power purchases directly from the grid [23]. In order to determine whether incentives for private entry exist, we devise a strategy to simulate operations of a hypothetical storage device.

3. Simulation approach

Our empirical approach is structured around maximizing the battery owner's operating profits. Let t index the year under analysis; P_t denote the price differential (call this the discharging premium) between charging and discharging SMPs in year t; S_t denote number of full cycles a battery completes in year t, as a function of the discharging premium, $S_t = S_t(P_t)$; S be the total cycle capacity in the battery over its useful life; r denote the interest rate and R^t the discount factor, $R^t = 1/(1 + r)^t$. Define $\pi_t = \pi_t(S_t) = \pi_t(S_t(P_t))$ as the net operating revenues per year as a function of the discharging premium that year.

Abstracting from the battery's fixed acquisition (capital) costs, the battery owner seeks to maximize operating revenues over the stream of P_t, given the lifetime capacity constraint S:

$$\underset{P_t}{\text{Max}} \quad \sum_t \pi_t(S_t(P_t)R^t) \tag{1}$$

$$\text{subject to} \quad \sum_t S_t(P_t) = S$$

We estimate the maximum operating revenues for our hypothetical storage device owner through a three-stage analysis. The first stage of this process involves using historic Korean electricity data from the years 2009–2011 to devise an optimal battery