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Economic analysis of a customer-installed energy storage system for both self-saving operation and demand response program participation in South Korea

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ABSTRACT

In recent years Energy Storage System (ESS) has become increasingly important, not only for reducing peak customer demand, but also for enhancing grid stability and reliability. In this manner, this paper performs an economic analysis when a customer-installed ESS is used to both reduce their peak demand and participate for grid stability and reliability in the South Korean Demand Response (DR) program. First, current government policies for accelerating the utilization of ESS and compensation rules of the DR program in South Korea are investigated. Then, an optimal operational strategy for ESS is developed to maximize profits from DR program participation while maintaining the ESS self-saving operation (peak shaving and arbitrage). Actual industry demand profiles are used to verify the effectiveness of the proposed operational strategy for ESS. Furthermore, sensitivity analysis is performed by varying the DR program conditions to facilitate ESS participation. Therefore, these suggestions provide an effective guideline to encourage more ESS to participate in DR program in the future.

1. Introduction

The growth of Energy Storage System (ESS) is expected to increase grid flexibility along with the fundamental changes in both supply and demand of the nation's electric grid in the future. Bloomberg New Energy Finance forecasts that 45 GW/81 GWh of ESS will be installed worldwide by 2024, excluding pumped hydro [1]. In South Korea, the Ministry of Trade, Industry, and Energy has announced a target of 1.7 GW of ESS by 2020, and forecasts that a combined 440 billion Korean Won (KRW), the official currency in South Korea, worth of new demand for ESS will be created by 2020 [2,3].

ESS is a system or device that enables the storage and supply of electrical energy at the required time. ESS not only enhances grid reliability, but also reduces the cost of electricity by storing energy during off-peak times for use at peak times [1]. Applications of ESS have been classified into five categories including Generation, Ancillary Service, Transmission & Distribution (T&D) Infrastructure Service, Renewable Integration, and Customer Energy Management Services [4,5]. In order to take advantages of ESS in various applications, it is important to utilize them as versatile as possible in various fields such as power generation, transmission and distribution, and customer stage [6–9].

In Generation, ESS is capable of transferring electrical energy from when the energy demand and prices are low, to when energy demand and prices are high. Electrical energy time-shift can be applied in the power generation stage to reduce energy production costs. In addition, ESS can provide supply capacity during peak demand times, thereby delaying the need for extra capacity. Therefore, it could reduce the cost of installing new equipment for generations [6].

Ancillary Service including Frequency Regulation (FR), Operating Reserve, Voltage Support, Black Start are required to maintain safe, reliable, and secure transmission of electricity on the grid [9–11]. ESS can be utilized for Ancillary Service by taking advantage of its fast response capability. FR is for maintaining the nominal frequency using reserve power. ESS is expected to play a significant role in FR, by responding automatically according to governor follow-up operation and automatic power generation control [12,13]. FR is compensated by a pay-for-performance rule, which reflects the amount of work performed for FR. Voltage Support service is an ability to provide active and reactive power support of ESS to maintain an operating voltage level in a system. Black Start is an ability to provide the stored energy of ESS for restoring part of the grid during blackouts, until it is synchronized to the grid. Operating Reserve is a function that provides back-up

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generation for the grid, when unexpected malfunctions occur in one (or multiple) power generation.

In the application of Renewable Integration, ESS can play a significant role to increase the penetration level of renewable energy generation by reducing short-duration and long-duration variability caused by its uncertain and intermittent nature [14–18]. The short-duration variability of renewable energy generation can be improved by performing ramping of the ESS to cancel out fluctuations. The ESS is charged and discharged to compensate for the rapid increase and decrease of renewable energy generation, respectively [19,20]. Furthermore, ESS is able to improve the long-duration variability of renewable energy generation. One of the challenges to increase the penetration rate of renewable energy generation in the grid is the temporal mismatch between generation and demand. However, combining renewable energy generation with ESS would be able to supply power in the required time frame and volume, and at a reasonable cost [20].

ESS incorporated in T&D Infrastructure Service is able to contribute to Transmission/Distribution Upgrade Deferral, Transmission Congestion Relief, and Voltage Support [5,6]. Transmission/Distribution Upgrade Deferral means that the operation of ESS reduces the peak demand, facilitating financial benefits by delaying (or avoiding) immediate investments in transmission or distribution system upgrades, which are needed to increase the load carrying capacity. In addition, ESS is capable of contributing to Transmission Congestion Relief, by reducing transmission congestion charges that could be increased as the demand and deployment of renewable energy generation increases. The ESS also assists in maintaining the operating voltage level, by preventing problems such as voltage dips, power spikes, flicker, undervoltage, and power surges.

Last, Customer Energy Management Services of ESS provides the opportunity for customers to manage their energy use, including Power Quality, Customer Electric Energy Time-shift, and Demand Charge Management [21]. The Power Quality service of ESS helps to prevent damage of customer-installed equipment from the voltage variation problems mentioned earlier. Customer Electric Energy Time-shift is able to save energy charges by arbitrage, where energy is stored in the ESS when electricity prices are low, and then this stored energy is used when the prices are high. Furthermore, ESS can provide Demand Charge Management, especially for customers that pay electricity charges separately for energy use and peak demand. The demand charge is determined by the customer's maximum power during specified demand periods, and this charge is then imposed identically on 12 successive months, from the month of renewing the peak demand. Therefore, reducing maximum power by the peak shaving operation of the ESS in Demand Charge Management can reduce the customer's electricity bill every month.

Among these applications, a customer-installed ESS can contribute to Generation and Ancillary Service through the Demand Response (DR) program simultaneously with Customer Energy Management Services [22,23]. DR provides an opportunity for customers to contribute to the operation of the electricity grid, by changing their normal consumption patterns in response to time-varying electricity prices or other forms of financial incentives [24–26]. The DR program is divided into time-based and incentive-based DRs. In a time-based DR, customers voluntarily reduce or shift their electricity usage, based on time-varying electricity price signals. In an incentive-based DR, customers are offered the opportunity to reduce their demands at a requested time for grid reliability by Independent System Operator (ISO). Similarly, the South Korean DR program is classified into Economic DR corresponding to the time-based DR and Reliability DR corresponding to the incentive-based DR [27,28]. The Economic DR provides electricity supply capacity in Generation while Reliability DR contributes to secure Operating Reserve of Ancillary Service.

Therefore, this paper performs an economic analysis when a customer-installed ESS is used to participate in DR program including Economic DR and Reliability DR in conjunction with Customer Energy Management Services including peak shaving (Demand Charge Management) and arbitrage (Customer Electric Energy Time-shift). First, current government policies and compensation rules are investigated, which are designed to accelerate the utilization of ESS in South Korea. Then, an optimal operational strategy of a customer-installed ESS is developed, to maximize both electricity charge savings and the profits from DR program participation. For this, the ESS is divided (virtually) into two sections, one for self-saving ESS operation, and the other for DR program participation. The operational strategy of each section of the ESS is developed and combined, to avoid conflicts between them. In addition, actual industry demand profiles are used to demonstrate the effectiveness of the proposed ESS operational strategy. Furthermore, sensitivity analysis is performed by varying the DR program conditions, to make ESS participation feasible. Therefore, this paper presents effective guidelines for encouraging more ESS to participate in DR program.

The remainder of study is organized as follows: Section 2 presents the current government policies and compensation rules for ESS, including the ESS exclusive tariff system and DR program in South Korea; Section 3 proposes an optimal operational strategy of ESS for maximizing profits in DR program participation, while maintaining the self-saving ESS operation through peak shaving and arbitrage; Section 4 verifies the proposed operational strategy by using actual industrial demand profiles with the ESS; Section 5 presents the results and a discussion of sensitivity analysis by varying the DR program conditions to increase ESS participation; Section 6 presents conclusions and possible future work.

2. Current government policies and compensation rules for ESS in South Korea

2.1. Government policies to accelerate the utilization of ESS

In South Korea, due to the national blackout in 2011, it has been a critical issue to maintain the reserve electric generating capacity (reserve margin) at a certain level. [29,30]. However, this reserve margin has been shrinking due to the recent increases in electricity demands [28]. Recently the government has pledged to reduce reliance on nuclear and coal-fired power plants, while simultaneously encouraging and promoting the use of renewable energy generation [31,32]. Therefore, ESS is highlighted as significant; not only to secure the reserve margin by reducing or shifting the peak demands, but also to increase the penetration level of renewable energy generation by reducing the variability of its uncertain and intermittent generation.

As of 2016, South Korea is the second largest user of ESS in the world. It has installed 291.4 MW (nameplate capacity) of ESS and has already completed 55 ESS-related projects [33]. Since the government announced their target of 30% ESS market share by 2020, mid and long-term roadmaps have been established to increase the penetration level of ESS in generation, transmission, distribution, and consumer levels. Table 1 summarizes the government's supporting policies that encourage ESS installations.

In this paper the economic benefits are investigated when a customer-installed ESS is used to maximize the profits of DR program participation, while maintaining the self-saving ESS operation. Therefore, details of the ESS exclusive tariff system are shown in Table 2, to calculate economic benefits of the self-saving ESS operation by peak shaving and arbitrage.

2.2. Rules and compensations of DR program

In South Korea, the DR program is considered one of the most promising methods to improve system flexibility, by accommodating variable generation sources in the electricity market. Although the rules of DR programs have mainly been determined by the government under the demand management regime, unlike other countries the