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Advanced Energy Storage Systems for Utilities
Case of Korea Electric Power

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SUMMARY

Korea Electric Power Corporation (KEPCO), the national utility of South Korea, is currently deploying the largest utility-based, battery energy storage system in the world. The system, when fully deployed in 2017, will total 500 megawatts (MW) in scale (Project), about the energy size of a small nuclear power plant. The total estimated cost of the Project is approximately USD$540M. The deployment was spurred by KEPCO's drive to squeeze operational inefficiencies out of their electrical system through leveraging a state of the art lithium-ion battery based energy storage system (BESS). In 2015, approximately 52 MW have been deployed and an additional 184 MW have been installed by end of January 2016. The remaining 264 MW will be deployed in 2016-17.

The BESS system improves the day-to-day operating efficiencies of KEPCO, demonstrating thus far an expected payback in the system within two years of deployment. In addition, there is positive environmental impact through reduction in carbon emissions and trade benefits that are accrued. While the regulatory environment between Korea and other parts of the world may be different, operations are similar and the project shows that early adopters of utility-scale BESS can materially benefit from the technology.

KEYWORDS

Korea Electric Power Company (KEPCO), Energy Storage System (ESS), Frequency Regulation, PCS, Battery Energy Storage System (BESS), EMS, Frequency Regulation, Li-ion battery, Lithium-ion battery.

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Introduction

Korea Electric Power Corporation (KEPCO), the national utility of South Korea, is currently deploying the largest utility-based, battery energy storage system in the world. The system, when fully deployed in 2017, will total 500 megawatts (MW) in scale (Project), about the energy size of a small nuclear power plant. The total estimated cost of the Project is approximately USD$540M [1]. The deployment was spurred by KEPCO's drive to squeeze operational inefficiencies out of their electrical system through leveraging a state of the art lithium-ion battery based energy storage system (BESS[1]). In 2015, approximately 52 MW have been deployed and an additional 184 MW have been installed by end of January 2016. The remaining 264 MW will be deployed in 2016-17.

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Why Energy Storage?

Electricity Supply = Demand: The operations of utilities are constrained by physics: generated electricity "just is", and therefore the supply and consumption must be matched. Electricity generation must be kept in balance in real time with demand—you cannot dispose easily of excess electricity. From the utility perspective, too much energy generation can lead to short circuits in the network and the over-heating of end-customer devices; and too little generation leads to brown-outs or even blackouts.

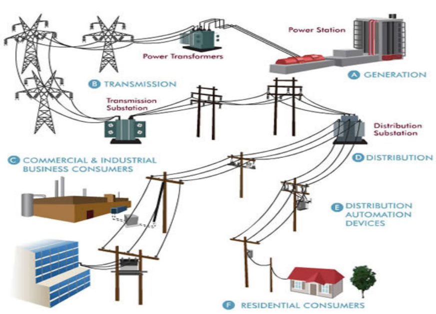

Figure 1: Electrical System Network *is composed of generating power assets, transmission and distribution infrastructure, and end customers. A core tenet of this complex operation is that power generation should equal customer demand in near real time. This leads to substantial network supply-demand fine-tuning known as frequency regulation, and stress points in the distribution and generation infrastructure during peak periods of demand. Significant cost is incurred by operators in the maintaining this balance.*

Frequency Regulation: The load matching imperatives lead to cost and complexity in the operation of utilities. Today's utilities on a real-time basis are required to manage their electrical generation to 99%+ accuracy relative to consumption. In KEPCO's case, this means that every two seconds they are monitoring electrical frequency across the country, and adjusting electrical generation up or down to fit within a 0.2 Hz tolerance level (59.8-60.2 Hz). Furthermore, certain utilities are required to operate at 90% accuracy level on a monthly average basis [2]. When there is too much power, generation plants are instructed to reduce output to bring the electrical current within the 60 Hz band; and when there is too little power, generators must increase output. The constant up and down pattern leads to excess production and increased wear and tear on power generation assets. This constant micro-tuning of output to meet the thin band is known as Frequency Regulation.

Peak Demand & Spinning Reserves: The peaks in electricity consumption, a result of daily or seasonal demand patterns, lead to material inefficiencies in the system. Specifically, utilities must hold in reserve a portion of their scheduled daily production capacity as a "spinning reserve". In KEPCO's case, each plant that is generating electricity at any given time reserves approximately 5% of their

[1] For purposes of this White Paper, BESS refers to lithium-Ion based battery energy storage systems, the type being deployed by KEPCO.

online output so that they can accommodate any sudden surge of demand or a production shut-down at another generating site; i.e., generators operate at most at 95% of their capacity. This reserve for KEPCO totals approximately 1,500 MW of capacity.

Peak vs. Capacity Build: Utilities must also plan for "over-build" capacity generation to accommodate these expected peak periods. The "over-build" capacity generation must be reserved even though this capacity is only needed for a very limited number of hours during the summer. Figure 4 compares the production capacity in peak, and average usage of KEPCO's facilities and shows only 60% of the generation assets are used on average.

Electricity consumption will vary substantially according to time of day (night vs day), season (summer peak), as well as year (whether it is a "hot year" or not). Sudden spikes of demand lead to extremely high marginal production costs that typically are either passed on to the customer (Peak Demand Charges) or absorbed by the utility. The costs can be substantial: in cases where Peak Demand Charges are passed on, they can equate to as much as half the cost of the electricity bill for relatively short bursts of time [3].

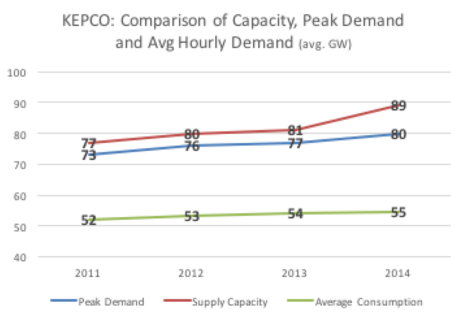

***Figure 4**: KEPCO average hourly demand was approx. 60% of capacity; and 68% of peak demand Source: KEPCO Annual Report 2014*

BESS Addresses Problem: Energy storage is based on the principle that it is more efficient to store excess energy and later discharge it in response to demand fluctuations, rather than constantly adjusting the generation load. In a sense, excess energy production is recycled through storage and discharged when needed. Lithium-ion battery storage addresses the shorter time-frame requirements where meeting near real-time demands is particularly important, including frequency regulation, peak demand management and power back-up. Lithium-ion batteries are particularly suited for these short time-frame applications given their high energy density, near real time responsiveness and declining costs akin to solar cells.

Genesis of KEPCO Project: The advances in lithium-ion battery technology led KEPCO to begin the design and implementation of its large-scale storage Project. The Company maintains approximately 1,000 MW in reserves in its generators to respond to frequency regulation, shorter bursts of peak requirements and power backup. As much as one-half of this amount, or 500 MW, will be replaced by energy storage systems. As this project is the largest utility-based energy storage system being implemented globally, we believe the project has broad implications for how utilities can manage their short time-frame applications, including frequency and peak requirements.

KEPCO BESS Project Incubation

KEPCO faced a number of hurdles to overcome in order to commence the project. First, the project had to receive appropriate regulatory approval. The Korean electrical system is structured as a separation of generation and distribution assets. Generation assets are independently operated, while distribution assets are largely in the hands of KEPCO. While the generation assets, as a whole, are majority owned by KEPCO, these power plants are operated independently under their own governance structure and accordingly have their own interests. The Korea Power Exchange ("KPX") is the main regulatory arm for managing the interface between the generation entities and KEPCO's distribution capacity, i.e. KPX manages the market being established between the operators and KEPCO as well as related systems. The KPX initially took the position that BESS was a generating asset, and therefore KEPCO, as a distribution company, could not own or operate the BESS. Eventually, the differences were worked out.

A second important factor was operational and financial viability. The latter was particularly important since the government, though the majority shareholder of KEPCO, insisted that the project be funded on its own by KEPCO. There was little precedent or track record in other countries for using BESS for frequency regulation. As a result, under the direction of Dr. Woohyun Hwang, Senior Vice President, KEPCO had initiated a USD$30M feasibility trial for testing the capacity of BESS. The feasibility trial was completed in 2013, and demonstrated the operational improvements and financial viability of BESS. On Jeju Island, KEPCO had implemented a 4 MW / 8 MWh battery project with a number of applications, including peak shaving, wind renewable power smoothing, and frequency regulation [4].

The alignment of the government's national interest was based on the following: a) cost-savings and compelling capital returns for the national utility; b) the development of a leading edge eco-system for energy storage consisting of batteries, power conversion, software and other BESS technology players; and c) the prospect of Korea leading the international development of BESS for frequency regulation through technology transfer, licensing, and exports.

KEPCO BESS Project and System Description

Background: KEPCO began implementation of its BESS project as a national project in December 2014. Approximately 52 MW was deployed in the first stage for testing and confirmation of the technology. With confirmation of system capability in May 2015, KEPCO recently installed an additional 184 MW of BESS capacity. The Company worked with its technology partners including EN Technologies, Samsung SDI, LG Chemical, and others for the design and integration of the system, especially the power conversion and battery systems and their linkage to the energy power management system of KEPCO.

BESS Architecture: As seen in Figure 5, the BESS is composed of three core components: a) Frequency Regulation Controller, which measures constantly in near real-time the frequency of the electricity at a given point on the grid and provides instructions for charging and discharging of the storage system; b) Power Conditioning System (PCS), which receives signals from the Frequency Control and communicates with the battery system on the extent of charges or discharges, and also converts the DC power of batteries into AC power for the grid (or vice-versa); and c) the battery system, including the battery management system, which stores energy which may be discharged through the PCS onto the grid. The system operates in real-time, with discharge/charge/hold decisions being made every four seconds. Furthermore, the system also should track the state of charge of all battery systems on the grid. For safety purposes, the system will also constantly monitor temperature and guard against overcharging, and take corrective action if needed.

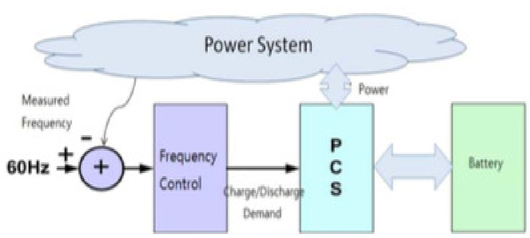

Figure 5: *The KEPCO BESS system architecturally consists of three main components: frequency control, power conversion and battery storage.*

Figure 6: *KEPCO deployment of BESS at the Shin-Yongin substation where 16 MW system designed and implemented by EN Technologies is installed.*

The system is modular in nature, with each BESS unit comprised of a 4 MW PCS together with 1 MWh battery system. This enables each unit to discharge 4 MW of energy for a maximum of 15 minutes. Each substation has between four and seven such modules, which are housed in containers. At full charge, the system is generally configured to cover any frequency reserve.

Figure 7: KEPCO national roll-out of BESS: *The map shows the current deployment of the BESS in Korea. The black stars represent BESS systems already implemented and the red stars represent BESS that is scheduled for installation in December of this year.*

Phase 1 involved the deployment of 52 MW at two sub-stations one hour outside of Seoul, while Phase 2 totals 184 MW at seven substations and eight sites spread through the country. Phase 2 installation was completed in January 2016.

In other markets, utilities, RTOs and ISOs have deployed energy storage systems at the customer site, along the distribution network (substation) or at the location of the generating plant. KEPCO chose to rollout BESS nationally at the substation level, enabling a more efficient coverage of the frequency regulation requirements and a higher level of safety vs. customer site location.

BESS Benefits and Considerations

Cost Reduction: KEPCO is able to reduce its spinning reserve needs through BESS adoption; as a result, it can shift more production to the lowest cost generating plants. The spinning reserve needs, normally 5%, can be cut by as much as a half, thereby allowing efficient plants that are generating power to operate at increased production capacity. KEPCO can increase compensation to power generators, often third-party vendors, for actual generation, while reducing spinning reserve and other fixed payments. These payment reductions are quantified below.

Power Quality: A second advantage is that the quality of the power improves materially. The BESS is able to respond in milliseconds to frequency regulation requirement. By contrast, reserves will take from 15 seconds to fifteen minutes, depending on the configuration of the reserve. Figure 8 shows a chart under actual test conditions shows the substantial speed difference between BESS and the incumbent reserve system (Automatic Generation Control or AGC[2]).

Environmental and Trade Impact: BESS is environmentally more conducive. Currently KEPCO is using mostly thermal coal as its spinning reserve and therefore any reduction in coal plant utilization can assist in carbon reduction and other environmental initiatives. Finally, as Korea is largely an energy importer, a greater use of BESS will reduce imports thereby helping in their trade balance.

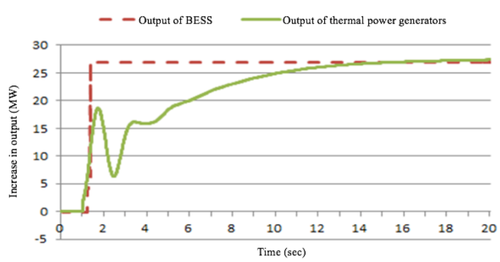

Figure 8: Test comparison of frequency regulation through BESS and the output of thermal power generation*. The BESS was able to output greater than 25 MW of power within 1/10 of a second, while thermal power generation took 12 seconds to reach this level. The current method results in material lags in a utilities ability to control frequency in real time.*

[2] AGC is an automated system that is capable of responding to grid frequency regulation requirements in 10 to 15 seconds through adjusting the output of the online power generators connected to the grid.

Other Considerations

BESS Costs: The price of lithium ion batteries, the lowest cost practical solution today for frequency regulation, has been dropping an estimated ten to fifteen percent per year. Today, the cost of a BESS is approximately USD$500/kWh, roughly one half the cost of 2012. Furthermore, costs are expected to decline further to the sub-USD$200/kWh range by 2020 as may be seen in analysts' forecasts in Figure 9. While costs today may still be a challenge for "storage-intensive" applications such as significant time shifting of solar or wind, they are low enough today, as may be seen below, to generate substantial cost benefits for short time-frame applications such as frequency regulation and short-time peak demand. We may anticipate that as batteries (lithium-ion or other) continue to decline in costs, the systems will have significantly more capacity and take on more applications where significant time shifting takes place, such as renewable energy.

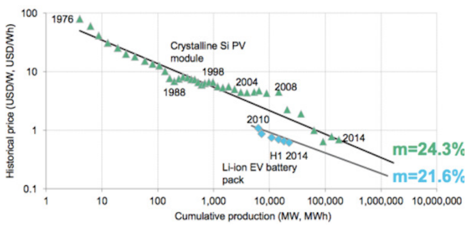

Figure 9: Lithium-Ion Cost Curve: *Over the last four years, the lithium-ion battery cost curve has been tracking the solar industry at similar stages of industry development. Costs of lithium-ion systems, which today can cost in the range of USD$500/kWh, are expected to fall to the sub-USD$200/kWh range within five years.*
Source: Bloomberg, other industry sources.

Safety: There have been incidents of fires bursting out from over-heated lithium-ion batteries. The technology has improved significantly since then including better chemistry (more gel-like rather than liquid, and with different chemical compositions that are less susceptible to burning), better temperature sensing, and safety features in the electronics to guard against system over-heating.

Economic Analysis of KEPCO BESS

This section is based principally on the analysis of the consultant, Korea Electrical Engineering and Science Research Institute (KESRI), who performed the technical and economic analysis review following completion of Phase 1 of the Project (52 MW, completed May 2015) [5].

Key assumptions are as follows:

- The investment costs of the Project are related to KEPCO's estimated capital costs of 500 MW BESS, or approximately USD$542M. We may view these as conservative, as current costs are at or below this number on a cost per MW basis and should decline over the succeeding years.
- Currently KEPCO has its power producers (most of them KEPCO affiliates) hold back approximately 5% of their online production capacity for frequency, backup and other reserve purposes. KEPCO compensates the online producers for the reserves at a standard marginal power rate less the fuel costs (based on coal consumption). The assumptions below on payment savings represent the amount that KEPCO will no longer be required to pay, as this reserve function would be assumed by the BESS.
- We have added O&M costs based on Sandia National labs estimate of O&M costs. This is in line with some previous studies analyzing the KEPCO related battery projects. We believe this to be extremely conservative as these estimates date to 2013 and battery systems have improved substantially since then, leading to expected lower O&M costs.
- We have assumed a ten-year life of the project and no residual value in the system. In fact, while there may be questions about whether the life of lithium-ion batteries can go to or beyond ten years, the remaining equipment (PCS, transformers) have 20+ year lives. We have also prepared a seven-year battery life return calculation.

Based on the above assumptions, the projected IRR of the project is in the 33-38% range and the estimated cash payback is less than three years. To date, indications are that these returns are being met in “live” implementation.

KEPCO BESS IRR										
USD MN	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Investment - BESS	-542									
Payment Savings		281	281	281	281	281	281	281	281	281
O&M Costs		-63	-63	-63	-63	-63	-63	-63	-63	-63
Gross Cash Flow	-542	218	218	218	218	218	218	218	218	218
Cumulative Gross CF	-542	-324	-106	112	330	548	765	983	1201	1419
IRR --10 Year	38%									
IRR --7 Years	33%									

Input Source: KESRI, “Report to KEPCO President, A Study on the Performance Verification and Project Vitalization Methods for a Pilot Project of F/R ESS” (Translated), May 2015; other industry sources.

Summary: Considerations for Local Utility

KEPCO is demonstrating that large-scale lithium-ion based energy storage systems are commercially viable for core utility requirements including frequency regulation, peak demand management and power backup. While the regulatory and industry framework in Korea may be different, we believe that there are a number of benefits KEPCO is deriving from BESS that can be applied to ISOs and RTOs. These include:

- A reduction of costs, especially for functions such as frequency regulation and peak demand management. The case of Korea has demonstrated that energy storage can be substantially more cost-effective than traditional spinning reserves.
- A more responsive grid that adapts quickly to sudden changes in supply or demand. The BESS does away with the lags of the traditional system for balancing generation with load.
- More efficient use of generation assets by moving away from legacy-based spinning and other reserve systems. There will be less “wear and tear” on generating assets and higher use of existing assets.

The KEPCO case also has application to utilities that may use external power supply. In such instances, lithium-ion based energy storage can help utilities defer transmission or distribution line investments through peak reduction, improve power quality for value customers, and integrate renewables more easily onto the local grid.

About Korea Electric Power Corporation

Korea Electric Power Corporation (KEPCO) is the world's seventh largest electric utility. The national utility serves over 12 million households and countless manufacturing and commercial facilities nationally. Their T&D transmission losses, a key indicator of efficiency, totaled 3.6% in 2014, among the lowest in the world. The Company also is active in the international projects, with 15 overseas power generation projects totaling nearly 19 GW of generation capacity. This includes an USD$18.6B contract to design and build nuclear power facilities of 5.6 GW capacity for UAE.

The Company is majority owned by the Korea Government and also publicly listed on the Korea Stock Exchange with ADRs traded on the NYSE. The Company's long-term credit rating is AA- by S&P and Aa3 by Moody's. The Company generated a net profit of USD$2.5B in 2014 on sales of USD$52B. Further details are available at www.kepco.co.kr

About EN Technologies, Inc.

Established in 2003, EN Technologies develops and markets products that shape, convert, and transform power. The Company has three product lines. The first is DC power supplies. Power supplies are needed for driving thin film manufacturing processes, including semiconductors, solar cells and LCDs OLED and touch panel displays. EN's power supply customers include some of the largest, most demanding global manufacturing companies, such as Samsung, LG, Canon, Sharp, Toshiba, Kyocera and others.

The Company also has a line of electrical switchgear, which is used by major infrastructure companies to protect their lines against power surges. Customers include Korea Electric Power, where the Company has won numerous supplier rewards, and Korea Railways. In addition, EN also exports switchgear to China, Taiwan, Thailand and the Middle East.

The Company has recently branched into energy storage, leveraging their knowledge of power flow and conversion to develop systems and products that are used by utilities as well as commercial and industrial customers to manage their electricity systems. EN was ranked by KEPCO as the qualified leader in their 52 MW energy storage project completed in May 2015. This project, currently the world's largest, will grow to 500 MW by 2017. To date, EN has completed 58 MW of power conversion projects, including the KEPCO BESS Project, which makes EN one of the world's largest such provider. EN is also building a second-generation suite of products for addressing commercial and industrial customers. These are scheduled for release in the first half of 2016.

EN's investors include Samsung, LG and the Korea Development Bank.

About Burns & McDonnell

Burns & McDonnell is a fully integrated engineering, architecture, construction, and environmental consulting firm with a multidisciplinary staff of more than 5,300 professionals worldwide. With annual revenues of $2.5 billion, we have large-firm resources but small-firm responsiveness. Because we are relationship-focused and dedicated to creating amazing success for our clients, we have a 90 percent repeat-business rate and client partnerships that span multiple decades. Clients appreciate the entrepreneurial ambition at Burns & McDonnell. Being 100 percent employee-owned means that everyone has an ownership stake in the success of our clients, and all team members are driven to find remarkable solutions.

BIBLIOGRAPHY

[1] Navigant Research, "In South Korea, an Energy Storage Bonanza", October 14, 2013.
[2] Brendan J. Kirby, Oakridge National Laboratories, "Frequency Regulation Basics and Trends", December 2004.
[3] Deizinger, David, US Department of Agriculture, Technology & Distribution Program, Dec 2000; peak demand charges have risen significantly since this date.
[4] Manuelito Del Castillo, Jr., Gun Pyo Lim, Yongbeum Yoon, Byunghoon Chang, "Application of Frequency Regulation Control on the 4MW/8MWh Battery Energy Storage System (BESS) in Jeju Island, Republic of Korea", Journal of Energy and Power Resources, Vol. 1, No. 6, 2014, pp. 287-295, December 30, 2014.
[5] KESRI, "Report to KEPCO President, A Study on the Performance Verification and Project Vitalization Methods for a Pilot Project of F/R ESS" (Translated), May 2015.