Article

A Case Study of Smart Grid Station in Guri Branch Office of KEPCO

Jaehong Whang [1], Woohyun Hwang [2], Yeuntae Yoo [3] and Gilsoo Jang [3,*]

[1] Graduate School of Energy and Environment, Korea University, Seoul 02841, Korea; jh_whang@korea.ac.kr
[2] Jeju Headquarters, Korea Electric Power Corporation, Jeju-do 63121, Korea; hblue@kepco.co.kr
[3] School of electrical Engineering, Korea University, Seoul 02841, Korea; yooynt@korea.ac.kr
* Correspondence: gjang@korea.ac.kr Tel.: +82-2-3290-3246

Abstract: Climate change and global warming are becoming important problems around the globe. To prevent these environmental problems, many countries try to reduce the emissions of greenhouse gases (GHG) and manage the consumption of energy. In Korea, Korea Electric Power Corporation (KEPCO) has introduced Smart Grid (SG) technologies to its branch office in 2014. This was the first demonstration of smart grid on a building called Smart Grid Station. This paper treats the achievements of the Smart Grid Station (SGS) by its early target in three aspects. The things are peak reduction, power consumption reduction and electricity fee saving. The authors analyzed the achievements by comparing the data of 2015 with the data of 2014. Through the evaluation, the authors studied the case, proved the advantages of SGS, and suggested the requirements to improve and the direction to go of the system.

Keywords: Smart grid, Smart Grid Station, renewable energy sources, energy management system

---

1. Introduction

For many years, concerns about global warming and climate change have been growing. In response to these environmental problems, most developed and developing countries have had meetings and looked for countermeasures. One of these efforts resulted in the Kyoto Protocol, an international treaty was adopted in 1997 and took effect in 2005. However, due to the expiration of the Kyoto Protocol in 2020 (Post2020), the Paris Agreement, a statement of intent to address climate change problems, was signed by 195 countries at the twenty-first Conference of the Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC), held in Paris, France, in 2015. The objective of the Paris Agreement was to hold the increase in the global average temperature to below a 2℃ above pre-industrial levels [1]. Unlike in the case of the Kyoto Protocol, it is significant that many countries attended the COP21 autonomously, and each country set its own target with regard to greenhouse gas (GHG) emissions. Table 1 shows the goals for GHG reduction of some selected countries. Although the United States declared a withdrawal from the agreement, other countries keep trying to contribute to the health of the environment.

Countries that signed the Paris Agreement summited their goals, called Intended Naturally Determined Contribution (INDC), for the reduction of GHG emissions in the Paris Agreement. Through the INDC, the Korean government set a goal to reduce GHG emissions by 37% compared to business as usual (BAU) by 2030 [5]. As an effort, the Korean government has tried to expand renewable energy generation and develop new technologies. One of the technologies is the Smart Grid (SG), which is a new concept of an electrical grid integrated with information and communication technologies (ICT). The SG is generally composed of distributed energy resources (DERs), such as photovoltaics (PVs) and wind turbines (WTs), Operation System, energy storage system (ESS), advanced metering infrastructure (AMI), and other smart devices [6]. The Operation System can balance supply and demand in real time by monitoring and controlling the whole system of a building.

Table 1. Goals of GHG Emissions Reduction for Selected Countries [2-5]

Countries	Goals
China	To lower carbon dioxide emissions per unit of GDP by 60% to 65% from the 2005 level
EU	At least 40% domestic reduction in GHG emissions by 2030 compared to 1990
Japan	At the level of GHG emission reductions of 26% by 2030 compared to 2013
South Korea	GHG emission reduction by 37% from the BAU level by 2030

Since 2009, Korea Electric Power Corporation (KEPCO) which is a public company has installed and demonstrated SG technologies. The Jeju Smart Grid Demonstration Project was the first test-bed built on Jeju Island in 2009. As a comprehensive project, this had five themes: Smart Place, Smart Transportation, Smart Renewable, Smart Power Grid, and Smart Service. It included renewable energy resources, metering, use of electric vehicle, battery system, demand response, transmission, communication, etc. Using the experience gained in the project, Smart Grid Station (SGS) was built in the Guri branch office building of KEPCO in 2014 as the first demonstration on building. Smart Grid Station is a term that combines smart grid with Station. Station means a place or a building that can provide various services. Therefore, Smart Grid Station is a place that provides intelligent electricity services to customers. KEPCO expects that the office can shave power peak and reduce power consumption. Since the demonstration, the KEPCO has expanded SGS to 121 of its branch offices. However, the expansion is limited in KEPCO's internal branch offices. In other words, although it has been a few years since the first SGS was built, the smart grid industry is stagnant in Korea. The authors recognized an analysis was required to verify the performance of SGS and to propose a direction based on an analysis comparing current real operation data with early expectations.

2. SGS Concept and Features

The objectives of SGS are to optimize the usage of electricity and to reduce the electricity fee and consumption in a building, with various integrated technologies.

When renewable energy resources connected to both grid and ESS generated power, the power from renewable energy can be supplied to load directly or charged ESS. Also, the battery is charged from grid when the price is low and discharged when the price of electricity on the grid is high. This allows a building to save money and reduce power consumption. In this system, less energy production is required by fossil fuel generators during times of peak consumption. In consequence, SGS benefits the environment by reducing emissions of CO_2. These effects are shown in Table 2.

Table 2. Details of SGS

Objective	Reducing consumption and saving electricity fee by optimizing usage in a building
Expected Effects	• Reduce 5.0% of electricity peak in a year • Reduce 9.6% of power consumption for a year • Save electricity fee • Reduce 5.0% of CO2 for a year
Features	• Remote control of demand in a building • Energy management system construction based on SG • ICT convergence on intelligent energy management

 doi:10.20944/preprints201805.0161.v1

The Guri SGS project consisted of two steps. The duration of the first step was from October, 2013 to February, 2014, and this step was for the installation of PV, ESS, a slow-charging type of EV charger, AMI, a smart distribution board, and building automation system (BAS) components. The goal of the first step was to optimize the building's energy consumption based on SG. The second step was for the addition of WT, control system of the heat, ventilation, and air conditioner (HVAC), and improving the Operation System. The duration of the second step was from December, 2014 to June, 2015.

Figure 1 is a diagram of SGS components. It shows the Operating System (OS), which is a software program that plays a key role in integrating other technologies. It can monitor and control each element remotely and maintain the power balance by communication between various components. In order to help small and mid-sized businesses, KEPCO adopted their products and integrated various systems as an ICT convergence. Each component will be specified in the Section 3.

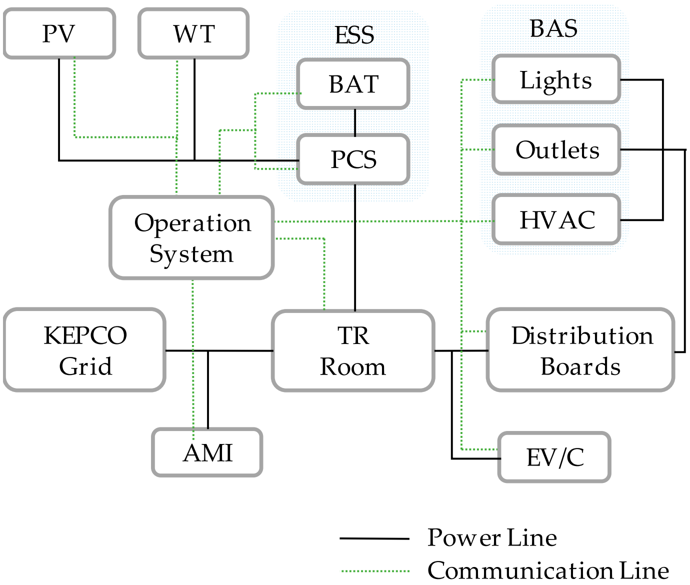

Figure 1. The main components of SGS

3. Components Description

3.1. Photovoltaic

The PV system was mounted at 30° on the rooftop. The maximum power of each module is 250W, and the total capacity of the system is 20kWp. The system is composed of 84 modules consisting of monocrystalline silicon cells, but 4 of them are dummies. The capacity was adopted at 5% of the contracted power (400kW) of the Guri office. The PV system supplies the power the building on weekdays, and charges a battery on weekends. Table 3 is the specification of the PV system.

Table 3. Specification of PV System

Device	Monocrystalline Silicon
Max Power	250Wp (60 Cells)
Max Voltage	497.6V (31.1V × 16)
Efficiency	15.7%
Capacity	20kWp (6 by 14, 84 modules, Dummy 4)
Connection	16 series by 5 parallel

The power from PV in summer season, from June to August, doesn't charge the battery but supply to building loads directly to reduce the peak and power consumption.

3.2. Wind Turbine

WT system was mounted on the rooftop from March, 2015. The PV system and the WT installed as Figure 2. This WT is not influenced by the direction of the wind since it is a vertical axis type wind turbines (VAWT) [7]. Also it doesn't make noise when the turbine rotates, and cut-in wind speed is light wind as 3m/s. These features make the WT system easy to install on buildings, but the rated power is 1.2kW at 15m/s. Although this WT generates 53kWh for a year by Weibull performance calculations, the system is hard to contribute to reduce energy because the wind doesn't blow fast enough in urban area.

Figure 2. PV and WT system at Guri Office

Because this vertical type of WT has unstable output at certain wind speeds and low efficiency [7,8], it has its own interconnected inverter to stabilize the output. Table 4 shows the features of WT, and Table 5 shows the details of this inverter.

Table 4. Performance Characteristics of WT

Type	Vertical Axis type
Size	1400×1800mm
Rated Power	1.2kW at 15m/s
Cut-in wind speed	3m/s
Extreme wind speed	52.5m/s

Table 5. Specification of WT Inverter

Input	Rated Voltage	430Vdc
	Voltage Range	60~600Vdc
Output	Max Capacity	3kW (Single Phase)
	Rated Voltage	220Vac (±10%)
	Rated Frequency	60Hz (±0.5Hz)
	Efficiency	98%
	Power Factor	99%

3.3. Energy Storage System

ESS is composed of a battery and power conversion system (PCS). Figure 3 shows the battery and PCS installed on the rooftop. The ESS can be used for either on-grid status or off-grid status. The ESS has various effects: peak shaving, load leveling, providing constant voltage and constant frequency (CVCF), cost reduction, load compensation and so on [9]. In this paper, the authors focused on peak shaving, and load shifting. Regarding of the first function, the ESS charges power from renewable energy (RE) resources at the off-peak load time and discharges the power at the peak time. Regarding the second function, the ESS charges a battery with the power from the grid in the evening and discharges the battery in the afternoon. By cutting peak and shifting load, the electricity fee can be saved.

The PCS converts DC-to-AC and AC-to-DC. This means that it can function both a converter and an inverter. Usually, a PV system has its own inverter, but the PCS used in the SGS is a hybrid type. Figure 4 is the inner connection diagram of PCS. It makes it possible to charge or discharge the power of the PV, the WT, and the battery. The capacity of the PCS was determined to be 30kW, considered the capacity of the PV and the battery, in that the PV system has 20kW, and the battery was estimated to discharge at 10kW.

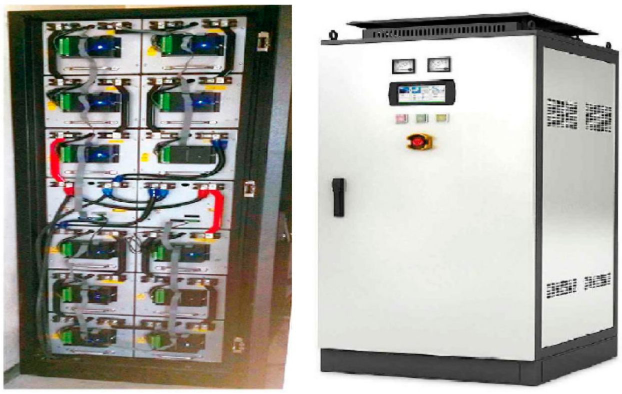

Figure 3. Battery (left) and PCS (right) on rooftop

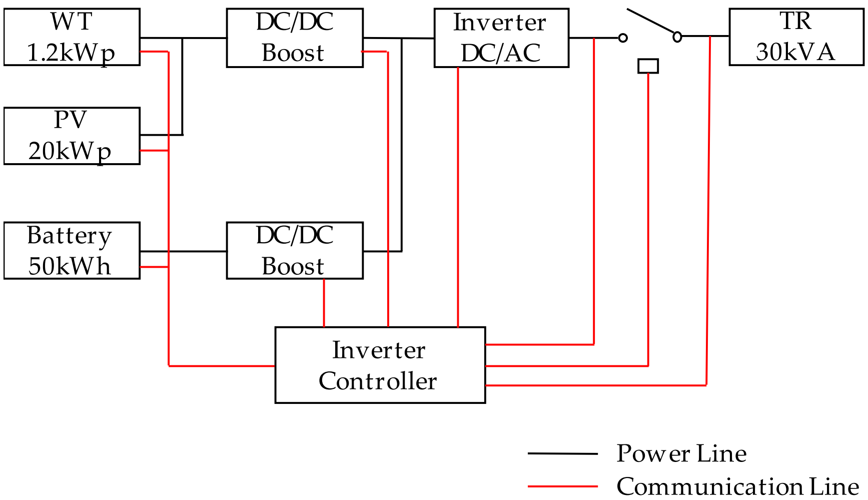

Figure 4. Battery (left) and PCS (right) on rooftop

A lithium iron phosphate (LiFePO4) battery was selected, and the size is 50kWh. LiFePO4 has better thermal and chemical safety than other types of batteries [10]. The capacity was designed to discharge for five hours at 10kW. The life cycle is 4,000 cycles at 80% of depth of discharge. This means that the battery can be used 4,000 times if it charges-and-discharges power in the range of 20% to a full charge state. This range is established to prevent the battery from reaching a full discharge state. The specification of the ESS is in Table 6.

There are three discharge schedules that the operator adjusts, and those are as follows:

1. Uniform discharge: Discharges uniform amount of power from battery during peak and mid-load times continuously

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 10 May 2018 doi:10.20944/preprints201805.0161.v1

2. Continuous differential discharge: Continuously discharges during peak and mid-load times, but the amount is different during peak load time
3. Non-continuous differential discharge: Discharges non-continuously during peak and mid-load times, and the amount is different during peak-load time

In summary, the ESS charges the batteries at the off-peak load time and discharges them during the peak and mid load times on weekdays. It is expected that a customer can reduce power peak by 5% with these schedules.

Table 6. Specification of ESS

PCS	Capacity	30kW/30kVA, 60Hz
	Control System	PWM converter
	Max Efficiency	90%
	Power Factor	Over 95%
	Max Input Voltage	800Vdc from Battery
		450~850Vdc from PV
	Output	45A
BAT	Capacity	50kWh (25kWh × 2)
	Charge-Discharge Efficiency	95%
	Cell Voltage	3.2V, 20Ah
	Rack Voltage	422.4V(11modules, 396 cells)
	Nominal Voltage	422.4V (369.6V~468.6V)

3.4. Advanced Metering Infrastructure

An AMI installed in a transformer room of the SGS measures the amount of power supplied from the grid and checks the qualities of voltage, current, and frequency. A general electricity meter monitors power quality every 15 minutes, but the AMI exports the data in real-time. The exported data are used to calculate the real-time electricity fee and analyze the operation status. This AMI is connected in series a connection to current, and in a parallel connection to voltage. Figure 5 shows the picture and the connection of the AMI, and Table 7 is the detail specification of the AMI.

Table 7. Specification of AMI

Potential Transformer	AC 10~452V/110V
Current Transformer	0.05~6A(rated 5A)
Measurement	Voltage, Current, Freq., etc.

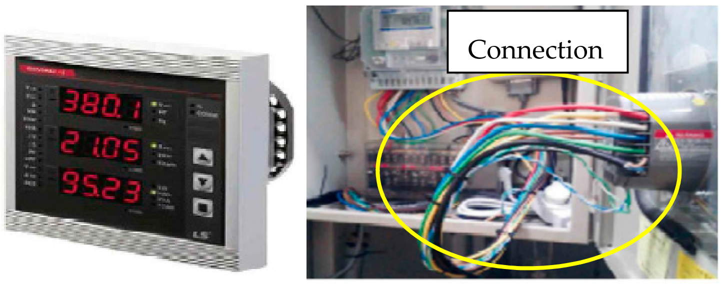

Figure 5. Pictures of AMI and connection line

3.5. Electric Vehicle Chargers

Outside of the building, there are 6 EV chargers. Four of them are a slow-charging type, and the others are a fast-charging type. The slow-charging type has an AC type of connector and charges the EV at 7~8kW through a single phase of 220 Vac, and it takes about 5 to 6 hours to reach a full charge.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 10 May 2018 doi:10.20944/preprints201805.0161.v1

The fast-charging type has 3 kinds of sockets: CHAdeMO, Combo, and 3-phase AC type. CHAdeMO and Combo supply power in DC. The fast-charging type chargers supply power at 50kW by 380~450Vdc or 380Vac. However, because of the inconvenience caused by different types of connectors, there is a trial to standardize the shapes of connectors currently. In fact, the EV chargers are considered as loads, but potentially, they can be bridges to implement the vehicle to grid (V2G) [11].

3.6. Building Automation System

For an automation system in a building, CTs are installed in each distribution board to measure the power quality and the consumed energy by the hour and by the device. Also, smart outlets and light switches were newly installed, and these can be controlled remotely by the Operation System.

The outlets can cut off standby power. Their rated allowable current is 16A, and their overload current is 20A. For the smart lighting, gateways were installed to transmit control signals to the lighting from the OS.

The other controllable system of the BAS is heating, ventilation, and air conditioning (HVAC). The OS adjusts the air quality by controlling the frequency of the variable frequency drives (VFDs) to reduce energy consumption.

To measure power consumption of each device, current transformers (CT) are installed in distribution panels. These CTs are solid-ring and split-core types, and they communicate with a multi-channel power meter by Modbus.

3.7. SGS Operation Sytstem

In the SGS, the Operation System plays a role as energy management system (EMS). This is a software program that can integrate the other components. These are connected in communication lines, and the data of the devices are gathered into the operation system. This means that the system can monitor the power consumption of all components in the building in real-time. Moreover, it has a human machine interface (HMI) that shows the details of the components. Figure 6 (a) shows that the OS has three categories: system configuration, management, and statistics. This is the main page of the OS, and from this page, an operator can select any other page.

The first page, system configuration, shows the real-time power flow. In this section, users can check the status of components and monitor the general data, including electricity fee information, supplied power from each source, and power consumption of the building. This helps users to understand the power flow, and Figure 6 (b) shows it. On this page, the operator reviews the overall function of the system. Figure 6 (c) includes the information on the communication status of each device.

The OS gathers various data from the devices in the communication by Modbus and Zigbee. Based on these data, the OS is able to turn each light switch and outlet on and off and to manage the PCS and BAS in the management section. Figure 6 (d) shows monitoring of the power consumption on each floor. Figure 6 (e) and (f) are control pages for lights and outlets. Figure 6 (g) and (h) show VFDs and HVAC.

Specifically, the operator can set schedules for these devices. Regarding the PCS, the OS controls the charge-discharge operation mode as shown in Table 8. The output of the WT is too small to contribute to the modes.

The statistics section comprises an overall analysis, DER analysis, and load forecasting. Overall analysis is for supplied power and peak per day, month, and year. Figure 6 (i) is the page of the monthly analysis of supply/demand. The DER analysis shows the PV generation and the amount of battery discharge. One of the main functions of the OS is to forecast the demand of electricity by its own algorithm. Through this analysis, the OS controls the devices and power flow, and decides to charge or discharge the battery.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 10 May 2018 doi:10.20944/preprints201805.0161.v1

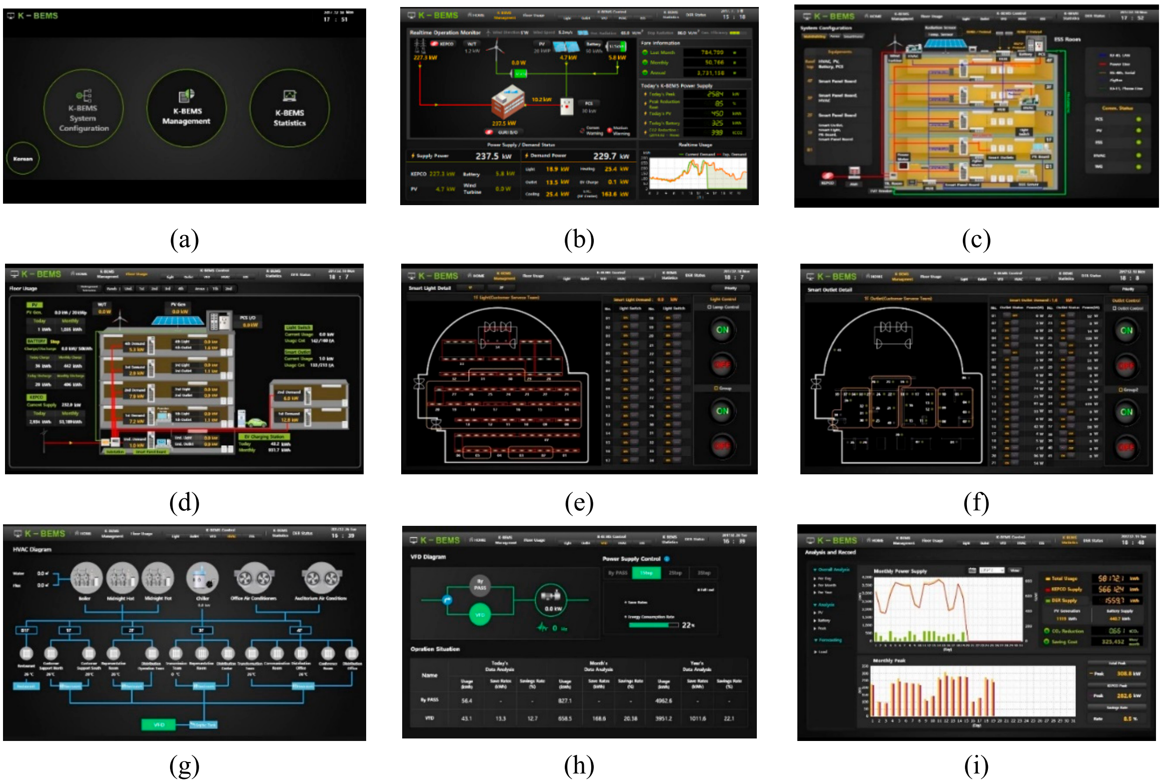

Figure 6. Operation System displays

Table 8. Operation Modes of PCS

Status	Mode	Description
Charge	Full charge	Full Charge by PV + Grid
	Only PV Charge	Charge by only PV
Discharge	Full discharge	Supply power to loads by PV + BAT
	Fix PCS output	•Fix PCS output •BAT output varies with PV output
	Fix BAT output	•Fix BAT output •PCS output varies with PV output
	Only PV discharge	Supply power to loads by only PV
Concurrent	Fix BAT charge	•Some of PV output charges BAT •Other supplies to loads
	Fix PCS output	•Some of PV output supplies to loads •Other charges BAT

4. Performance Evaluation

To evaluate the performance of Smart Grid Station, the authors analyzed the reduction of peak and consumption, as well as, economy by comparison with the early targets.

The performance analysis is based on Smart Grid Station operation algorithm shown in Figure 7. Following the algorithm, power from KEPCO grid charges the battery at off-peak load times, such as night time or on weekends. Also, if the generation of the PV and WT is over the power demand, the extra power goes to charge the battery. On the other hand, the grid power, renewable energy sources, and battery supply to loads, including the EV/C, outlets, lights, and HVAC, at the peak-load time and mid-load time. The Operation System gathers and monitors these generating, supplying, and demanding data.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 10 May 2018 doi:10.20944/preprints201805.0161.v1

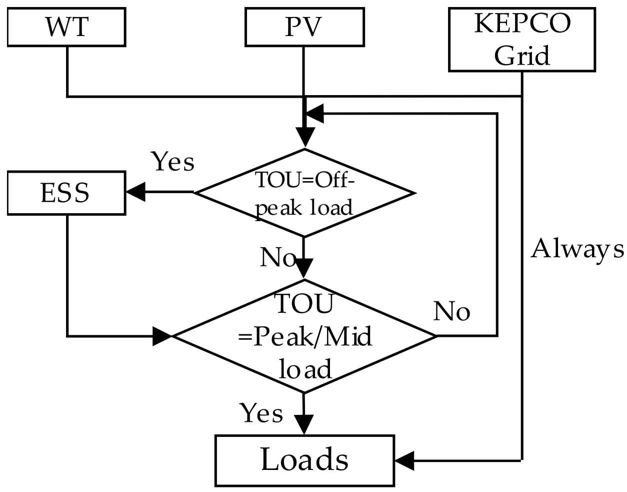

Figure 7. Smart grid Station Operation Algorithm

In the SGS, the peak power and consumption are reduced due to the DER. This makes it difficult to directly compare the decreased value with the unreduced value that could have been measured if not for the reduction. For this reason, the authors tried to compare the reduced peak and consumption with the values from 2014; however, new equipment and appliances were installed in the supervisory control and data acquisition (SCADA) room and the temporary office of the city of Namyangju in the Guri branch office, and we considered these changes in increment. Table 9 shows the details of increment in the building, and the authors assume usage time of the devices as in Table 10.

As the equipment for the SCADA room is ICT equipment, it is always used, even on weekends. Because the air conditioning system is an ice storage system, it does not contribute to a rise in the peak. Printers and cooling fans were considered to be unused during peak time to save energy.

Table 9. Newly Installed Equipment and Appliances

	Installation Date	Items	Capacity (kW)	Using hours		Consumption		
				Per a weekday	Per a weekend	Aug (kWh)	Sept (kWh)	Total (kWh)
SCADA	2014 10.30	Media Rack	0.72	24	24	10,460.6	10,123.2	20,583.8
		Audio Rack	0.5					
		6 DLP Cube	1.32					
		4 LED TVs	0.52					
		Humidifier	11					
Temp. office	2015 03.24	Lights	1.8	10	-	378	360	738
		13 Computers (400W)	5.2	10	-	1,092	1,040	2,132
		13 Computers (300W)	3.9	10	-	819	780	1,599
		21 Monitors (170W)	3.7	10	-	777	740	1,517
		Hot&Cold dispenser	0.85	24	24	632.4	612	1,244.4
		Air Handling Unit	12.5	10	-	2,625	2,500	5,125
		10 Cooling Fans	0.3	6	-	37.8	36	73.8
		4 Printers (700W)	2.8	1	-	58.8	56	114.8
		Ice Storage AC Sys.	15	10	-	3,150	3,000	6150
Total Consumption(kWh)						20,030.6	19,247.2	39,277.8
The number of weekdays in each month						21 days	20 days	
The number of weekends in each month						10 days	10 days	

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 10 May 2018 doi:10.20944/preprints201805.0161.v1

Table 10. Details of Usage Time

	Usage hours			Note
	Off-peak load	**Mid load**	**Peak load**	
SCADA	6	8	10	All days
Office Facilities[1]	6	3.5	0.5	08:30~18:30 on Weekdays
Hot&Cold Dispenser	6	8	10	All days
Ice Storage AC System	-	-	10	Weekdays
Printers	1	-	-	Weekdays
Cooling fans	5	1	-	Weekdays

[1] Lights, computers, monitors, and air handling unit

4.1. Peak Shaving

For a commercial building, once a peak power is measured, the peak is adopted for the electricity fee in the year. The maximum peak occurred in the summer. Thus, the authors compared the peak that occurred in August and September of 2014 with the peak in same months of 2015 as Table 11.

Table 11. Comparison of Peak

	Day Peak [kW]	Evening Peak [kW]	Max Peak [kW]
'15.08	285.12	294.24	294.24
'15.09	255.84	213.12	
'14.08	271.08	259.56	271.08
'14.09	255.96	237.24	

Peak shaving ratio (PSR) is a ratio between the maximum peak in 2015 and the maximum peak in 2014.

$$Peak_{add} = 42.01\text{kW} \times 0.9 \cong 37.8\text{kW} \quad (1)$$

$$\text{PSR}(\%) = \left| \frac{Peak_{max}^{2015} - Peak_{add}}{Peak_{max}^{2014}} \times 100 - 100 \right| \quad (2)$$

$$\text{PSR}(\%) = \left| \frac{294.24 - 37.8}{271.08} \times 100 - 100 \right| = 5.40\% \quad (3)$$

In (1), 42.01kW is a sum of the capacity of all equipment except cooling fans, printers, and the ice storage AC system in Table 9. The value of added equipment capacity defined in (1) should be subtracted from max peak in 2015. This value is an estimate of the capacity multiplied by the power factor (0.9). In (1) and (2), the result of the PSR is 5.40%. This means that the early target of 5% reduction in peak has been surpassed.

4.2. Consumption Reduction

The second effect of the SGS is the reduction of power consumption. The data used to calculate peak reduction in Section 4.1 was also used in this section.

The consumption is separated into three time periods: off-peak load, mid load, and peak load, as shown in Table 12. The added power consumption is subtracted from the total consumption in 2015. The consumption reduction ratio (CRR) is calculated in (5). In (4) and (5), the result is approximately 11.26%. This indicates that the initial target is also achieved.

Table 12. Monthly Consumption

	Consumption (kWh)			
	Off-peak load	Mid load	Peak load	Total
'15.08	24,299	20,703	19,128	123,807
'15.09	27,478	17,619	14,580	
'14.08	7,844	21,322	18,891	99,686
'14.09	17,695	19,343	14,591	

$$Con_{add} = 39{,}277.8kWh \times 0.9 \cong 35{,}350kWh \quad (4)$$

$$\text{CRR}(\%) = \left| \frac{Con_{max}^{2015} - Con_{add}}{Con_{max}^{2014}} \times 100 - 100 \right| \quad (5)$$

$$\text{CRR}(\%) = \left| \frac{123{,}807 - 35{,}350}{99{,}686} \times 100 - 100 \right| = 11.26 \quad (6)$$

4.3. Saved Electricity Fee

There are two kinds of electric rates: demand charge and energy charge. Demand charge is for the peak measured, and energy charge is different in each season. Time periods are divided into summer, spring/fall, and winter. Exact time periods are shown in Table 13.

Table 13. Segmentation by Season and Time [12]

Load Time	Summer	Spring/Fall	Winter
Off-peak load time	23:00~09:00 23:00~09:00		23:00~09:00
Mid load Time	09:00~10:00 12:00~13:00 17:00~23:00		09:00~10:00 12:00~17:00 20:00~22:00
Peak load time	10:00~12:00 13:00~17:00		10:00~12:00 17:00~20:00 22:00~23:00

Electric rate refers to each type of customers. General Service rate which is classified in General Service (A) I, General Service (A) II and General Service (B) is for building customers. These rates are subdivided into High-Voltage A for 3.3kV to 66kV and High-Voltage B ranged over 154kV. Besides, customers can choose option I, option II or option III depending on the customers' electricity using time for a month. The High-Voltage A option II of General Service (B) is for the customers who use electricity for 200~500 hours per month, and whose contract demand of 300kW or more. The details are shown on Table 14.

Table 14. Electric Rates Table for High-Voltage A Option II of General Service (B) [12]

Demand charge	8,320 won/kW			
	Time period	Off-peak load	Mid Load	Peak Load
Energy charge (won/kWh)	Summer (Jun.1~Aug.31)	56.1	109.0	191.1
	Spring/Fall (Mar.1~May.31/ Sep.1~Oct.31)	56.1	78.6	109.3
	Winter (Nov.1~Feb.28)	63.1	109.2	166.7

Each of total power consumption and electricity fee in 2014 and 2015 is on Table 15. To calculate the Saved Fee Ratio (SFR), the added fees were also considered. These fees are on Table 16 and Table 17. By (7), the sum of added fees is 4,127,892won, and the FRR is calculated as 10.15%.

$$Fee_{add} = Charge_{demand} + Charge_{energy} \tag{7}$$

$$\mathrm{SFR}(\%) = \left|\frac{Fee^{2015} - Fee_{add}}{Fee^{2014}} \times 100 - 100\right| \tag{8}$$

$$\mathrm{SFR}(\%) = \left|\frac{15{,}924{,}000 - 4{,}127{,}892}{13{,}128{,}000} \times 100 - 100\right| = 10.15\% \tag{9}$$

Although there was not an early target for fee reduction, the analysis of electricity fees is enough to prove the effects of the Smart Grid Station.

Table 15. Total Electricity Fee in 2014 and 2015

Date	Consumption (kWh)	Fee (won)	Total (won)
’15.08	64,130	8,659,000	15,924,000
’15.09	59,677	7,265,000	
’14.08	48,057	6,424,000	13,128,000
’14.09	51,629	6,704,000	

Table 16. Demand Charge for Added Loads in 2015

Month	Max Peak	Demand Charge	Charged Fee
Aug	37.8kW	8,320 won/kW	314,496won
Sept	37.8kW	8,320 won/kW	314,496won

Table 17. Energy Charge for Added Loads in 2015

2015		Consumption (kWh)	Fee [1] (won)
Aug	Off-peak Load	7744	304,041
	Mid load	5481.4	387,755
	Peak load	6021.0	761,778
	Total	19247.2	1,453,574
Sept	Off-peak Load	8056.7	406,783
	Mid load	5695.8	558,758
	Peak load	6278.2	1,079,785
	Total	20030.7	2,045,326

[1] 0.9 of power factor is applied in the Fee, and decimal point is rounded up

5. Economic Analysis of Smart Grid Station

In Section 5, we studied the contribution with regard to the economic aspects, especially the contributions of PV generation, EV, and energy time shifting by the ESS.

5.1. Saved Electricity Fee by PV generation

During August and September of 2015, PV generation was 2,961.5kWh in August and 2,326.1kWh in September. The total saved fee is the sum of saved demand charge (SDC) and saved energy charge (SEC), contributed by PV system.

$$\mathrm{SDC} = P_{PCS}^{Max}(\mathrm{kW}) \times Charge_{demand} \tag{10}$$

$$\mathrm{SEC} = W_{DER}(\mathrm{kWh}) \times Charge_{energy} \tag{11}$$

It is difficult to know when the PV system generated power and how much the system generated. For this reason, the authors assumed the PV supplied power to loads at peak-load time and mid-load time in ratio of 8 to 2. Using the information above and (11), the SDC and the SEC in August were found to be as follows:

$$\mathrm{SDC} = 30\mathrm{kW} \times 8{,}320\mathrm{won/kW} = 249{,}600\mathrm{won} \quad (12)$$

$$SEC_{Aug} = 2{,}961.5\mathrm{kWh} \times (191.1\mathrm{won/kWh} \times 0.8 + 109.0\mathrm{won/kWh} \times 0.2) = 517{,}374\mathrm{won} \quad (13)$$

The SDC values from September are the same as those from August. Likewise, the SEC values from September are as follows:

$$SEC_{Sept} = 2{,}326.1\mathrm{kWh} \times (109.3\mathrm{won/kWh} \times 0.8 + 78.6\mathrm{won/kWh} \times 0.2) = 239{,}960\mathrm{won} \quad (14)$$

In conclusion, the total saved fee is 1,256,534 won.

5.2. Running Cost Reduction by EV

There was one electric vehicle in 2015, and the running data is on Table 18. In August and September, the EV ran in 470km and 345km, respectively. We assumed the fuel efficiency of a gasoline-powered car is 10km/L. Referring to the data, we compared the running cost (RC) of the EV with that of a gasoline-powered vehicle.

Table 18. Running Data of EV in 2015

Month	Mileage	EV charge Amount (kWh)	Price of 1kWh (won/kWh)	Price of Gasoline [1] (won/L)
Aug	470km	105.8	109	1,560
Sept	345km	68.4	78.6	1,590

[1] The price of gasoline is the average value of the month

$$RC_{Gas} = \frac{\mathrm{mileage(kW)}}{\mathrm{km/L}} \times Price_{Gasoline} \quad (15)$$

$$RC_{EV} = W_{EVcharge} \times Price_{W} \quad (16)$$

By substituting figures, the results are as follows:

$$RC_{Gas}^{Aug} = \frac{470\mathrm{kW}}{10\mathrm{km/L}} \times 1{,}560 won/L = 73{,}320\ won \quad (17)$$

$$RC_{EV}^{Aug} = 105.8\mathrm{kWh} \times 109 won/kWh \cong 11{,}533\ won \quad (18)$$

$$RC_{Gas}^{Sept} = \frac{345\mathrm{kW}}{10\mathrm{km/L}} \times 1{,}590 won/L = 54{,}855\ won \quad (19)$$

$$RC_{EV}^{Sept} = 68.4\mathrm{kWh} \times 78.6 won/kWh \cong 5{,}377\ won \quad (20)$$

Using (17) and (18), 61,787 won were saved, which means about 84.3% of the running cost was saved by the EV in August. These equations also show that 49,478 won, about 90.2% of the cost, were saved in September. Although the actual amount saved is small, this shows that the EV is much more effective than a gasoline-powered vehicle.

5.3. Saved Fee by ESS Scheduling

A customer charges the battery of the ESS at night, when the price of electricity is low, and discharges the power at the peak load time or mid load time when the price is highs. However, the power from PV system doesn't charge the battery but supplies power to the building load directly in the summer to maximize the efficiency. In August, 758.9kWh was charged to the battery, and same amount was discharged. In September, 541.1kWh was charged and discharged. Also we adapted the same assumption stated in *Section 5.1*. Equation (21) is a formula to calculate the fee reduction (FR). Time of use (TOU) applied in this equation is an electricity fee policy that varies with seasons and times, as shown in Table 14.

$$\mathrm{FR} = \left(W_{discharge} \times \mathrm{TOU}\right) - \left(W_{charge} \times fee_{off-peak}\right) \quad (21)$$

By substituting figures, the results are as follows:

$$FR_{Aug} = [758.9 \times (191.1 \times 0.8 + 109.0 \times 0.2)] - (758.9 \times 56.1) \cong 89{,}991 \text{ won} \quad (22)$$

$$FR_{Sept} = [541.1 \times (109.3 \times 0.8 + 78.6 \times 0.2)] - (541.1 \times 56.1) \cong 26{,}465 \text{ won} \quad (23)$$

As the calculations show, 116,456 won was saved for two months. By load shifting, the cost of electricity was greatly reduced.

6. Discussion

The authors verified the performance and economic feasibility of the Smart Grid Station to propose a future strategy. The performance was evaluated with regard to three aspects: peak shaving, reduction of power consumption, and electricity fee saving. Also, the economic efficiency was feasible in terms of electricity fee and running cost of the EV. Measured values in 2015 are revised for objective comparisons with values in 2014 before the SGS was built.

As described in *Sections 4* and *5*, the effectiveness of the SGS has been proven. However, smart grid technology is led by KEPCO in Korea, and the expansion of the technology is otherwise stagnant. This is because public institutions are leading the SG industry without supporting price policies for devices, and the private sector dose not participate in the industries actively, despite the effectiveness of the SGS. To support the expansion of SG, the convenience, safety and efficiency of SGS should be improved for customers. Also through the upgrade of the EMS, the system can integrate and control more various devices and technologies. To fulfill these requirements, the government needs to establish supporting policies.

7. Conclusions

As climate has changed, many countries have tried to prevent negative environmental impact. One of the efforts made toward this end is the smart grid. In Korea, KEPCO is evolving the SG technologies and expanding them to most of its branch offices. In this paper, the authors studied the first demonstration of SGS in the Guri branch office to prove the effectiveness.

The early main targets were a 5% reduction of peak, a 9.6% reduction of consumption, and savings in electricity fees. To evaluate the performance objectively, we compared the factors in 2015 with the values in 2014, while considering the increased loads in 2015. These operational analyses confirmed that peak was reduced by 5.40%, consumption by 11.26%, and fees by 10.15%. Also the economic analysis shows that the SGS is an effective solution for a building. Considering its effectiveness, we suggest the expansion of the SGS to more customers. By expanding it to the private sector, smart grid will contribute to the building of a smart city, which is a city-sized of energy solution. As a next step, the authors will study SG policies and the improvements.

Author Contributions: Jaehong Whang designed and wrote the paper. Woohyun Hwang supported and helped to collect the data. Yeuntae Yoo and Gilsoo Jang conducted the review. Gilsoo Jang contributed to the modification. All the authors have read and approved the final manuscript.

Acknowledgments: This work was supported by Korea Electric Power Corporation (R17XA05-4) and under the framework of international cooperation program managed by National Research Foundation of Korea (No. 2017K1A4A3013579).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. *ADOPTION OF THE PARIS AGREEMENT*, UNFCCC, Paris, France, 2015
2. *Enhanced Actions on Climate Change*, Department of Climate Change, national Development & Reform Commission of China, Beijing, China, 2015.
3. *SUBMISSION BY LATVIA AND THE EUROPEAN COMMISSION ON BEHALF OF THE EUROPEAN UNION AND ITS MEMBER STATES*, Latvian Presidency of the Council of the European Union, 2015.
4. *Submission of Japan's Intended Nationally Determined Contribution*, Japan, 2015.
5. *Submission by the Republic of Korea Intended Nationally Determined Contribution*, Korea, 2015.

 doi:10.20944/preprints201805.0161.v1

6. S. Borlase, “Smart Grid Technologies,” in *Smart Grids Infrastructure, Technology, and Solutions;* CRC Press: Boca Raton, FL, USA, 2015; pp.79-125, 978-1-4398-2905-9
7. M. Ragheb, “Vertical Axis Wind Turbines,” University of Illinois at Urbana-Champaign, 2011.
8. J. Fadil, Soedibyo, and M. Ashari, “Performance Comparison of Vertical Axis and Horizontal Axis Wind Turbines To Get Optimum Power Output,” *2017 15th International Conference on Quality in Research: International Symposium on Electrical and Computer Engineering*, **2017**, pp. 429-433.
9. A. Mohd, E. Ortjohann, A. Schmelter, N. Hamsic, and D. Morton, “Challenges in Integrating Distributed Energy Storage Systems into Future Smart Grid,” in *Proc. IEEE ISIE,* Cambridge, U.K., Jun. 30-Jul. 2, **2008**, pp.1627-1632.
10. E. Alegria, T. Brown, E. Minear, and R. H. Laseter, “CERTS Migcrogrid Demonstration With Large-Scale Energy Storage and Renewable Generation,” *IEEE Trans. Smart Grid,* vol.5, no.2, pp. 937-943, Mar. 2014.
11. K. M. Tan, V. K. Ramachandaramurthy, and J. Y. Yong, “Integration of electric vehicles in smart grid: A review on vehicle to grid technologies and optimization techniques,” *Renewable and Sustainable Energy Reviews,* vol.53, pp.720-732, Jan. 2016.
12. KEPCO General Service Electricity rate table. Available online: http://cyber.kepco.co.kr/ckepco/front/jsp/CY/E/E/CYEEHP00202.jsp (accessd on 09 May 2018).