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Research on the operation of DC microgrids

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Abstract: This study presents a demonstration project named DC Island. The project is demonstration study for the design, construction and operation of a DC microgrid. The site is one of an island in Republic of Korea and inhabited by about hundred peoples. It has electrically islanded power system from main land. Purpose of the project is to verify advantages of DC system through real operating test. Three factors are measured by the operating test to verify the advantages. Energy efficiency, voltage holding ratio and fuel consumption are the factors. Both measurement data and simulation results are used to draw a conclusion. Design, construction and operation results are described in this study. Capacity of distributed energy resources, DC line specification, DC network configuration, performance of converters and DC load systems are presented. Finally, analysis of the test results is given and the significance of the demonstration project is considered.

1 Introduction

Distributed energy resource (DERs) based DC such as photovoltaic (PV), energy storage system (ESS) and DC customers such as electric vehicle (EV), Internet Data Centre are recently increasing in power distribution networks. The demand for DC power distribution technology is increasing as a solution to integrate such facilities efficiently [1–3]. In addition, DC system has advantage in less loss and voltage control. Therefore, when used for specific cases such as long distance line, DC system is more feasible than AC system.

Korea Electric Power Corporation (KEPCO) Research Institute has been performing research to apply DC technologies in power distribution network. Development of equipment model such as converters, breakers and operation model such as Energy Management System (EMS), protection coordination is in progress. Low voltage direct current (LVDC) test-bed is installed in KEPCO's Power Testing Centre to verify DC prototypes. Demonstration test of LVDC distribution line is performed at inhabited area which has long distance line and low load.

Since 2016, DC Island project is performed and the commissioning test is completed in 2019. Grid for a small-scale island which has separated power system from main land, has many advantage for doing business of DC system. It has high generation cost, weak frequency stability and good condition to utilise renewable energy. One of an island named Geochado in Republic of Korea is selected for demonstration site of the DC distribution system project.

2 Design of DC Island

Introduction of demonstration site

Demonstration site is a small island located south sea of main land. Main source was three diesel generators before the DC project. The generators are aged so only two are on operation and one is used for backup. Maximum load of the island is over 300 kW so the power supply was unstable. Table 1 shows general status of the island before DC project.

Fig. 1 shows existing power plant and three aged diesel generators. To overcome unstable power supply, new additional DERs are designed and installed as part of DC project.

DC network configuration

Fig. 2 shows equipment and network configuration of DC Island. PV, WT, ESS and variable speed diesel generator (VSDG) are additionally installed and connected with DC distribution line. VSDG system with power conversion system is developed to connect with DC line. This system operates with automatic variable frequency which is optimal fuel consumption point. This is possible in DC system because synchronisation is not necessary. Capacities of DERs are determined by economic simulation using HOMER. Renewable fraction 70% constraint is applied considering CO_2 emissions. Fig. 2 shows the result of HOMER simulation [4] (Fig. 3).

Purpose of demonstration

Following three goals are set for DC project:

- Voltage holding ratio (over 99%).
- VSDG fuel consumption decrease verification.
- Energy efficiency improvement (over 10%).

Voltage holding ratio is calculated as per KEPCO's voltage operation regulation. Fuel consumption of VSDG is compared with normal DG. Energy efficiency compared DC system with AC system from source to end of load (including home appliance).

3 System construction

Distributed energy resources and power supply

Fig. 4 shows capacity and operation mode of DERs. Not all loads are directly connected to DC line. Twelve customers are selected among 70 customers in an island and connected to new DC grid ('New DC grid' in Fig. 4). Rest of loads are still left in main AC grid ('Main AC grid' in Fig. 4). Both of the two grids are connected through AC/DC converter. So, generated power from DERs can supply to existing main AC grid.

Main source in DC link is ESS and its converter hold reference voltage 750 Vdc. PV and WT operate as maximum power point

Table 1 General status of demonstration Island

Category	Contents
general status	location: island 24 km from main land population: 100 persons (70 homes)
power facilities	diesel generators 150 kW×3ea 380/6.6 kV transformers×2es
customers	general customers and public facilities purification plant and drying plant
load status	average: 124 kW maximum: 305 kW

a b

Fig. 1

(a) Existing power plant of the island, *(b)* Aged three diesel generators

Fig. 2 *Equipment and network configuration of DC Island*

Fig. 3 *HOMER simulation result for DC Island*

tracking mode. VSDG run as constant current mode in DC side and variable frequency mode in AC side.

DC distribution line

The type of cables was selected considering status of the demonstration site such as capacity, strength of electric pole, damage from see wind and so on. New DC cable was installed on existing electric poles under existing AC 6.6 kV as shown in Fig. 5.

For integration of DERs, ACSR 160sq. is used for DC 750 V because of high capacity of PV and WT. Rest of the lines are used

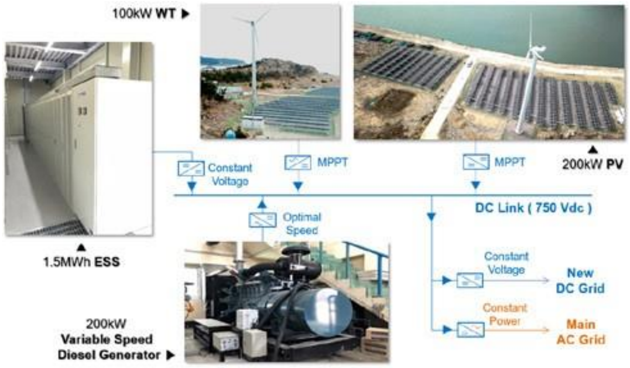

Fig. 4 *DERs and power supply configuration in DC Island*

Fig. 5 *DC line installation on electric pole*

Table 2 HOMER simulation result for DC Island

Voltage level	Line for connect	Wire type
±750 Vdc	long distance customer	F-CV 70/50sq. 3Core x 1-Line
±190 Vdc	short distance customer	F-CV 16/25/50sq. 3Core x 1-Line
750 Vdc	WT and PV	ACSR-AW/OC 160sq. x 2-Line

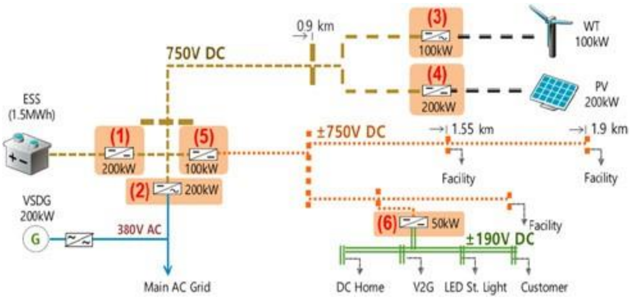

Fig. 6 *Capacity and configuration of converters*

by F-CV Cable 12–70 square, considering capacity of each load. Table 2 shows wire type as per voltage level.

Converters

Six kinds of converters are developed for DC Island as shown in Fig. 6. Specification of each converter is shown in Table 3. All efficiencies are based on factory acceptance test (FAT).

AC/DC hybrid customers

For 12 AC/DC hybrid customers (‘New DC grid’ in Fig. 4), AC/DC distribution panel is installed at each customer to supply AC or DC power. If DC system shut down, customer can use AC power by

Table 3 Specification of converters of DC Island

No.	Connect for	Type	Capacity	Input Volt.	Output Volt.	Eff., %
(1)	ESS	DC→DC	200 kW	493–639 Vdc	750 Vdc	97.3
(2)	VSDG	AC→AC	200 kW	380 $V_{3\Phi-ac}$	380 $V_{3\Phi-ac}$	97.7
(3)	WT	AC→DC	100 kW	380 $V_{3\Phi-ac}$	750 Vdc	96
(4)	PV	DC→DC	200 kW	500–741 Vdc	750 Vdc	98.04
(5)	bipolar	DC→DC	100 kW	750 Vdc	±750 Vdc	96.12
(6)	DC home	DC→DC	50 kW	±750 Vdc	±190 Vdc	97.14

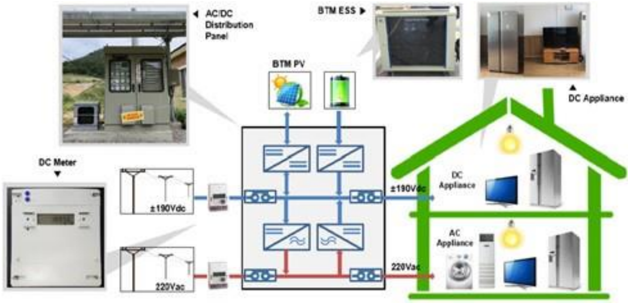

Fig. 7 *Configuration of AC/DC hybrid customer*

Fig. 8 *EV, V2G station and LED street light in DC Island*

Fig. 9 *EV, V2G station and LED street light in DC Island*

switching mode at the panel. Behind the meter (BTM) ESS and PV, DC meter, DC appliance (TV, refrigerator, LED light) are also developed and installed for the customers (Fig. 7).

DC public establishments

Thirteen LED street lights, five EVs and three V2G stations are installed and connected to DC system to test various types of DC loads (Fig. 8).

Fig. 10 *HMI of EMS for DC Island*

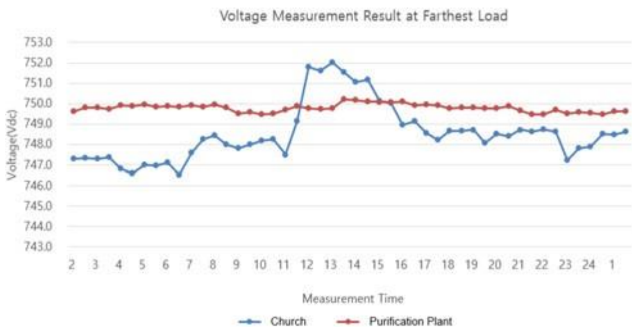

Fig. 11 *Voltage measurement result at farthest loads*

DC control centre

New control centre for DC Island is constructed. First flower is for power facilities such as ESS, converters, breakers, battery cells. Operating room, server room and model house of DC customer are installed. Solar heat plate is located on rooftop to support heating system of the building (Fig. 9).

DC energy management system

EMS for DC Island is developed and tested. Data interface, DB, HMI for DC network are developed. Monitoring and control of all converters can be done by the EMS. Six kinds of DC applications are developed and under the site test. The applications provide solutions such as real-time network analysis, DERs optimal output scheduling, SOC management and voltage control (Fig. 10).

4 Operation result

Voltage holding ratio

To verify voltage holding ratio, voltage is measured at AC/DC distribution panel of each 12 AC/DC hybrid customers. Fig. 11 shows the voltage measurement result at two customers. Church is the farthest load which is located 2 km from main converter (constant voltage control point). Voltage fluctuation is under 1%

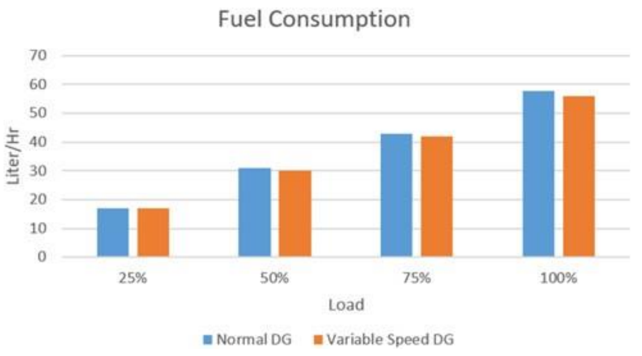

Fig. 12 *Comparison of fuel consumption at each loads*

Table 4 AC versus DC system comparison of energy efficiency

Section		DC	AC
DERs (PV, WT, ESS) interface efficiency (%)		95.87	94.18
transmission (4.03 km) efficiency (%)		88.21	80.58
customer efficiency	DC/DC converter efficiency (%)	97.14	100
	DC appliance efficiency (%)	100	93.60
total efficiency (%)		82.15	71.03
difference of efficiency (%)		11.11% ▴	

as shown in Fig. 11. Over voltage measurement during day time (12:00–15:00) is because of the BTM ESS and PV in customer. Voltage holding ratio at all 12 customers measured over 99% during the operation test.

Fuel consumption

Fig. 12 shows comparison of fuel consumption with normal DG and VSDG at each loads. Loss at converter of VSDG is considered. Maximum 3% fuel consumption decrease is measured at 100% load case. Therefore, DC system has advantage at operating cost by using VSDG.

Energy efficiency

Table 4 shows energy efficiency from source to appliance in customer. Efficiency of DER is based on FAT result. Transmission efficiency is based on both measurement and simulation result because measuring point is not installed at all DC lines. DC/DC converter data at customer is based on FAT and appliance efficiency is based on data from appliance manufacturer. Finally, energy efficiency of DC system increased 11.11% compared with AC system.

5 Conclusion

Introduction, design, construction and test results of DC Island project are presented in this paper. DERs, DC line, converters and DC customer systems are designed and installed considering the site condition. To verify advantage of DC system, voltage holding ratio, fuel consumption and energy efficiency are analysed based on the measurement data of operation test. As per the result, DC system is more competitive in voltage stability, fuel cost and efficiency. In future work, advanced DC application for EMS will be developed and tested to ensure higher reliability of DC system.

6 References

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