# APPLICATION OF LVDC DISTRIBUTION SWITCHBOARD SYSTEM WITH NEW AND RENEWABLE ENERGY SOURCE ON THE DEMONSTRATION SITE

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## *ABSTRACT*

*LVDC distribution is a technology that improves energy efficiency and supply confidence of the entire system by reducing the AC/DC conversion stage and changing from a distributed low efficient AC/DC conversion system to a centralized high DC/DC conversion system. This paper develops 380V low voltage distribution switchboard system components contains the development operation method of intelligent electric device (IED) for LVDC distribution for buildings with high reliability and efficient operation through field testing of the demonstration site.*

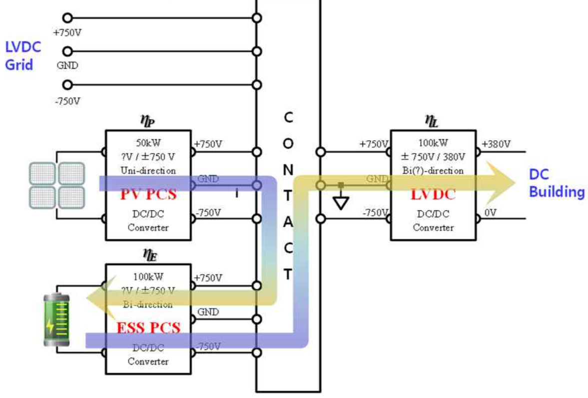
## INTRODUCTION

LVDC(Low Voltage Direct Current) distribution is a technology that improves energy efficiency and supply confidence of the entire system by reducing the AC/DC conversion stage and changing from a distributed low efficient AC/DC conversion system to a centralized high DC/DC conversion system. Although LVDC has a smaller power conversion stage than AC system, DC distribution network of small groups with LVDC facilities connected to one DC/DC converter is largely dependent on the overall efficiency of the distribution network system and therefore requires higher efficiency characteristics. Advances in technology require the storage of electric energy through ESS, the introduction of high-quality, high-reliability buildings such as IDC, and the supply of independent power networks such as microgrids and effective system connection. As DC system can be solved instead of AC system, and electricity technology has developed, there is a huge decrease in the need to stick to AC system. Accordingly, KEPCO research institute plans to develop a LVDC distribution switchboard system to supply high-efficiency, reliable voltage to respond to the emergence of large-capacity DC buildings and apply it to LVDC demonstration sites. The details are as follows:1) development 100kW high efficiency, insulated bi-directional DC/DC Converter for LVDC Power Distribution Building 2) development of distributed power utility system for buildings (30kW PCS system, 100kW ESS system) 3) design of distribution board system for distributed power and load power supply 4) development of IED for efficient operation and system interface of distribution systems 5) verification of LVDC switchboard for LVDC distribution system.

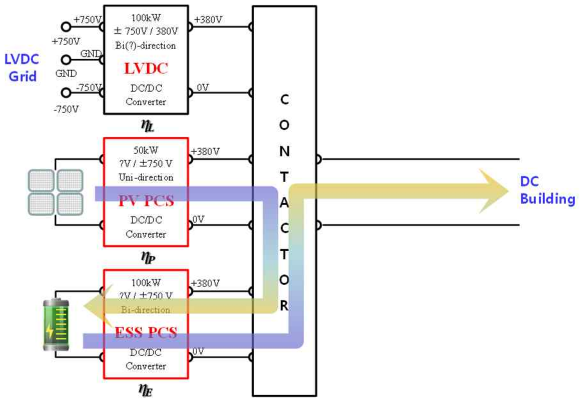
## DESIGN OF SWTICHBOARD SYSTEM

In order to configuration a large-capacity building switchboard system suitable for LVDC distribution, efficiency was analyzed through various power flow analysis of switchboards. As shown in Figure 1, two cases can be considered depending on the level of the voltage connected to the switchboard. Each case is supplied with ±750V by DC distribution and supplied to 380V DC building, including power conditioning system(PCS) for photovoltaic(PV) and energy storage system(ESS). The ±750V DC voltage converter equipment is called the LVDC converter and its efficiency is $\eta_L$. The ESS PCS efficiency is $\eta_E$ and the PV is $\eta_p$. In most situations, the conversion process is the same and the efficiency is not different, but the difference can be seen considering the situation in which the PV's power surplus is charged to the ESS and then discharged by necessity and supplied to the DC building load, as in the figure 1. The efficiency of Figure 1 case1 goes through the following conversion process $\eta = (\eta_p \times \eta_E) \times (\eta_E \times \eta_L)$. The effieciency of Case2 is $\eta = (\eta_p \times \eta_E) \times \eta_E$. In the case of independent operation without LVDC distribution voltage, this will happen frequently, and considering this, it is very important. Therefore, it can be seen that it is efficient to set the connection panel of the switchboard based on $380V_{dc}$. This paper designed the configuration of the switchboard and each detailed converter was designed based on case2.

**Figures 1.** Configuration of Switchboard for LVDC




(a) Case 1

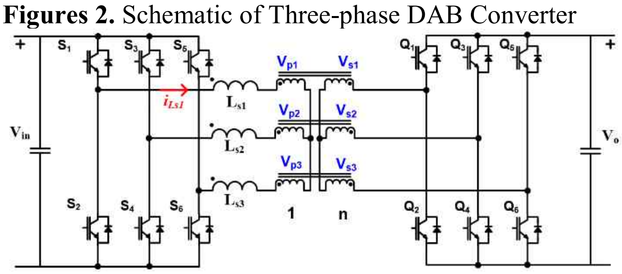



(b) Case 2

## Grid Connected DC/DC Converter

To achieve high efficiency goals, switching loss was reduced through selection of components and topologies. In the bipolar LVDC distribution system, topology was selected that can operate bi-directional power flow and perform normal operation when single-line except for neutral line fault. As shown in Figure 2, a 3-phase dual active bridge (DAB) converter was selected in consideration of economy and efficiency, although switching loss was reduced with a somewhat limited zero voltage switching (ZVS).

**Figures 2.** Schematic of Three-phase DAB Converter




The 100kW LVDC bi-directional DAB converter is designed to control and operate the master and slave converter by using two 50kW DAB converters. In a bi-directional DAB converter for LVDC, the high voltage (± 750V) part is connected in series, and the low voltage (380V) part is connected in parallel to supply the power. Because the low voltage stage is parallel, the operation may be shaken at the time of individual control, so one module drives the master and the rest drives the slave. When a module designated as a master of two catches the voltage of the input/output stage through voltage control, the other module operates in the current control mode and supplies power to the load. In addition, a soft start control technique must be installed to separate and control the mast converter and slave converter. If one module fails, it is decided to use current sensor cross-sharing method that is easy to use in the other part. Figures 3 and Table 1 show the module configuration and detailed specifications of the bi-directional 100kW LVDC converter.

**Figures 3.** Configuration of 100kW DAB Converter

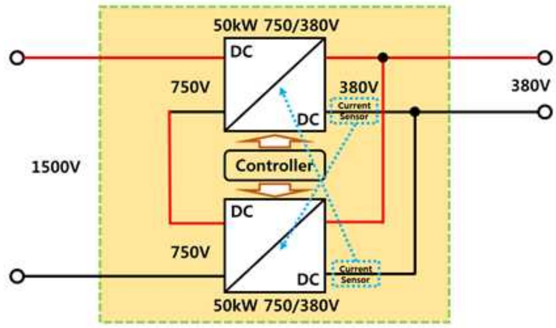



**Table 1.** Grid Connected DAB Converter Specification.

| Configuration | | Specification |
|---|---|---|
| Input | Rated Voltage | 620 ~ 800$V_{dc}$ |
| | Rated Current | 67A |
| | Rated Power | 100kW |
| Output | Rated Voltage | 380$V_{dc}$ |
| | Rated Current | 263A |
| | Rated Power | 100kW |
| | Overload Capacity | 110% for 1min |
| | Efficiency | ≥ 97% |
| Control Method | | 3-Phase Shift |
| Switching Frequency | | 8kHz |

## DC/DC Converter for ESS

When the interleaved Buck & Boost converter is applied, the ripple current reduction effect can be achieved inversely in proportion to the size of the multiple phase. In addition, the capacity of the output stage capacitor can be reduced as well as the loss reduction due to low equivalent series resistance (ESR) of the output capacitor can be improved to improve efficiency. Considering the duty ratio and ease of circuit deployment according to Input/Output voltage control, this paper applied a three-phase method. To charge the battery (412 to 630V) from the 380$V_{dc}$ line, the converter switches to Boost mode, and the duty ranges between 9% and 40%. The more the battery is charged, the less the ripple current is reduced and the converter loss is minimized. Figures 4 and Table 2 show the configuration and detailed specifications of the 100kW bi-directional interleaved converter.

**Figures 4.** Configuration of 100kW Interleaved Converter

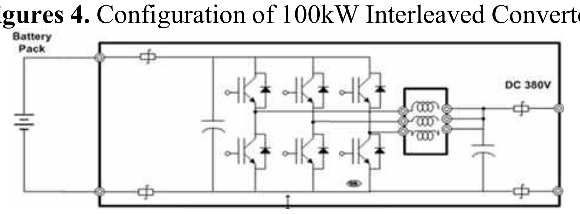


**Table 2.** DC/DC Converter Specification for ESS.

| Configuration | | Specification |
|---|---|---|
| Battery Input | Rated Voltage | 412 ~ 630$V_{dc}$ |
| | Rated Current | 182A |
| | Rated Power | 100kWAh |
| Output | Rated Voltage | 380$V_{dc}$ |
| | Rated Current | 264A |
| | Rated Power | 100kW |
| | Overload Capacity | 110% for 1min |
| | Efficiency | ≥ 97% |
| Control Method | | 3-Interleave PWM |
| Switching Frequency | | 5kHz |

## DC/DC Converter for PV

The converter for PV has the same topology as the converter for ESS. In addition, to minimize ripple current by applying 3-phase interleaved method in the power mode, MPPT voltage of 450 to 820 $V_{dc}$ is located by selecting cell voltage to have a symmetrical range based on 570 V because the voltage varies depending on the amount of sunlight. Table3 shows the configuration and detailed specifications of the 30kW Interleaved converter.

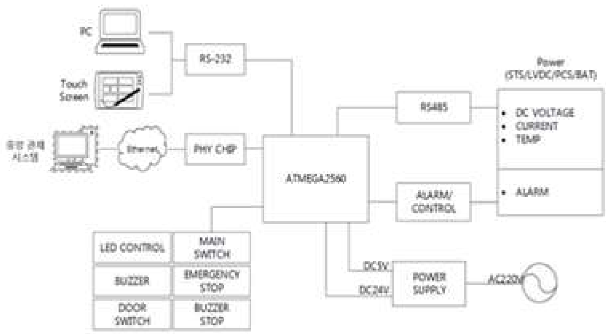
**Tables 3.** DC/DC Converter Specification for PV.

| Configuration | | Specification |
|---|---|---|
| PV Input | Rated Voltage | 900 $V_{dc}$ |
| | MPPT Voltage | 450 ~ 820 $V_{dc}$ |
| | Rated Power | 100kWAh |
| Output | Rated Voltage | 380Vdc |
| | Rated Current | 79A |
| | Rated Power | 30kW |
| | Overload Capacity | 110% for 1min |
| | Efficiency | ≥ 97% |
| Control Method | | 3-Interleave PWM |
| Switching Frequency | | 5kHz |

## Intelligent Electric Device (IED)

In a 380V LVDC distribution system, the power source consists of a LVDC converter that converts 380V from ±750V, a converter for a 30kW PV, and three converter for a 100kW ESS. It is required to be the main power source in the PV converter of the solar power system and to supply system power through the LVDC converter if power is not supplied from the PV or capacity is insufficient. ESS is charged when there is surplus power in the 380V system. However, the system (Energy Management System) or the IED determines the discharge operation. IED will stabilize the voltage of the LVDC converter for three power sources when the power is received from the distributed power source on the 380V grid. This means that the LVDC converter controls the voltage for the 380V grid, and the PV and ESS supply power to the 380V grid through current control. If the LVDC converter fails or does not operate, the ESS operates as a voltage source, and the PV supplies the generated power continuously through current control. The PV converter is responsible for generating maximum power through MPPT control, and when excess power is generated, it either charges the ESS or sends power to the ±750V LVDC grid through the LVDC converter. The IED's CPU is equipped with ATMEGA2560, which is divided into Ethernet communication for communication with the upper control system, RS485 communications for communication with the lower end LVDC, PV, ESS, STS, RS232 communications for real-time monitoring and debugging, and alarm to control LEDs or SWITCH on racks. The overall block diagram of the IED is shown in Figures 5.

**Figures 5.** IED Block Diagram



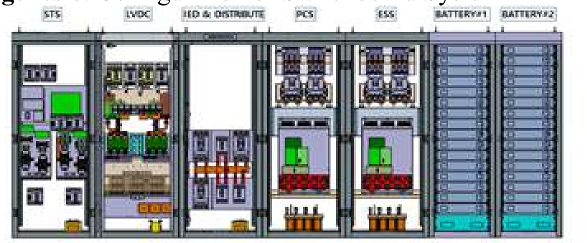

## PRODUCTION OF SWTICHBOARD SYSTEM

The LVDC distribution switchboard as a whole has the following composition.

1) 100kW Main Converter ±750V / 380V Bi-directional
2) 380V LVDC Distribution Board and IED Controller
3) 30kW PV DC/DC Converter
4) 100kW bi-directional ESS DC/DC Converter
5) 48kWh battery × 2rack

Figures 6 shows the configuration of the switchboard system and the 3D drawing. Equipment manufactured on this basis is installed on the LVDC distribution demonstration site owned by KEPCO for performance verification.

**Figures 6.** Configuration of Switchboard System

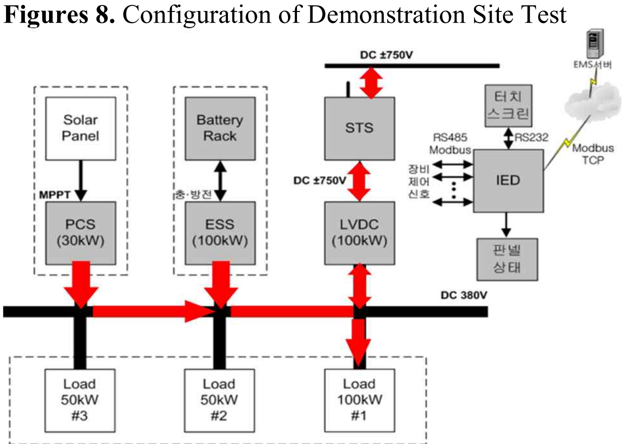



**Figures 7.** LVDC Demonstration Site Installation

## TEST RESULT OF DEMONSTRATION SITE

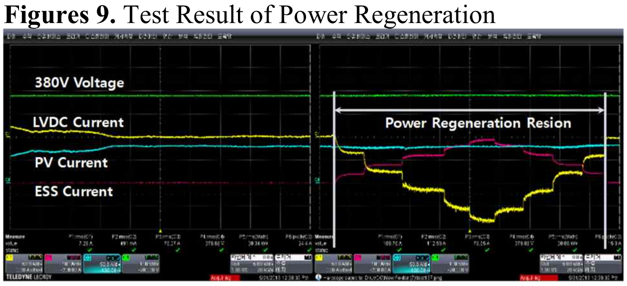
The detailed performance of each equipment was verified through factory acceptance testing (FAT), and the LVDC distribution demonstration site test was conducted to verify that the switchboard system maintains constant voltage in various scenario operations. This section shows typical test results among several scenarios. For the experiment, the simulation load for the 380Vdc of the demonstration site was utilized, and the figure 8 shows LOAD # 1.

**Figures 8.** Configuration of Demonstration Site Test

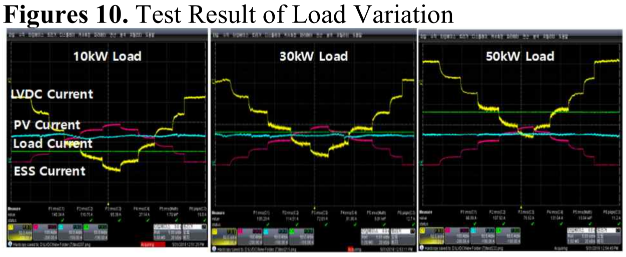



The test scenario for maintaining a constant voltage when controlling the bi-directional power flow of the LVDC converter is as follows. In load situations where 30kW is consumed, the PV converter generates its maximum output of 30kW. At this time, The power of the converter for ESS is controlled arbitrarily to discharge the power between 0 and 70 kW. when there is no power supply, It will supply power from PV up to 30kW and supply power to LVDC when PV power is lower than 30kW. However, if additional power is generated from the battery when a constant 30kW PV supply is supplied to the load, it is represented by the regenerative power of the LVDC converter. The test results for this are the same as Figure 9. As the output current of the ESS is increased with the PV current fixed constant, it can be confirmed that the current of the LVDC is regenerated in reverse direction. At this time, it can be confirmed that the 380V voltage is kept constant. Figure 10 is the same as the previous situation, but changdes the amount of the load and verifies the bi-directional power control and output voltage constant control performance of the LVDC converter.

**Figures 9.** Test Result of Power Regeneration




**Figures 10.** Test Result of Load Variation




## CONCLUSION

This paper develops 380V low voltage distribution switchboard system components contains the development operation method of intelligent electric device (IED) for LVDC distribution for buildings with high reliability and efficient operation through field testing of the demonstration site. In addition, KEPCO is testing the performance of independent driving, and now it feels a few seconds blackout in the load when converting from grid-connected driving to independent driving mode or reverse. The final goal is to switch over to mode without a blackout. The study of the LVDC large-capacity switchboard system is now in its infancy and it is expected that a lot of research on the operating algorithm for efficient and stable long-term operation is needed.

## ACKNOWLEDGEMENTS

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