DESIGN AND CONSTRUCTION OF KOREAN LVDC DISTRIBUTION SYSTEM FOR SUPPLYING DC POWER TO CUSTOMER

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ABSTRACT

The percentage of digital loads is constantly increasing against the analog loads and the interconnection of renewable energy sources is expanding in power distribution system. For these reasons, there are many researches concerning DC distribution system recently because significant gains like efficiency, stability, reliability and controllability can achieved by transferring to the DC (Direct Current) from the AC (Alternative Current) in power system. Especially, the IDC (Internet Data Center) has already shown the efficiency improvement effect of the DC distribution system. In addition, the study of DC homes has proven the superiority of the DC distribution system with changed AC to DC in home appliance feeding power system. This current trend is towards power utilities which supply electricity to customers. It is expected that DC customers like IDC (Internet Data Center), DC building and DC home will demand power utilities to provide the direct DC electric power at early date. Therefore, KEPCO (Korea Electric Power Corporation) which is the Korea electric utility has a plan to construct the LVDC (Low Voltage Direct Current) distribution system for supply DC power to the customer. This paper presents the design and construction plan of LVDC distribution system.

INTRODUCTION

EPRI (Electric Power Research Institute) expects that the percentage of digital load against analog load will increase explosively to 50[%] in 2020, which was 10[%] in 2000. Thus, the energy efficiency for digital loads is becoming important issue. The huge advantage of DC distribution system compared with existing AC distribution system is high efficiency caused by reduction of the number of AC-DC conversion units. Practically, in case of data center, total loss of DC distribution system reduces 17[%] than existing AC distribution system. In case of the interconnection with renewable energy sources in DC distribution system, such a photovoltaic and a fuel cell, power conversion is reduced 2stage (DC-DC) from 3stage (DC-DC-AC). Doing so would eliminate conversions, each of which saves between 2.5[%] and 10[%] of the developed energy. Therefore, DC distribution system has an abundant economic benefit.

In addition, it is expected that DC distribution system will have the improvement stability, reliability and controllability in distribution power system with reactive power non-existence, battery storage and power electronics. Moreover, DC distribution system is an environment-friendly system. Environmental concerns pose strong requirements on electricity production, which is responsible for a major portion of carbon dioxide (CO2) and other harmful emissions. By increasing the use of renewable energy sources to produce electricity, emissions can be reduced. Inefficient use of electricity, e.g., power losses, also contributes to emissions: for one kWh utilized, more than one kWh has to be produced, with consequent release of CO2 if the energy comes from fossil fuels. Therefore, DC distribution system would be a solution of global warming and reduction of fossil fuel. For these reasons, DC distribution system is expected to gradually spread to homes and buildings.

This current DC trend is towards Electric Power Utilities. It is expected that they will be confronted with huge demands that many DC customers want to receive the DC power directly from them. If utilities supply DC power to customer like DC home, DC building and IDC, the energy efficiency of whole electric power system will be increased. Therefore, electric power utilities should develop the technology for providing DC power to the customer.

KEPCO (Korea Electric Power Corporation) which is the Korea electric utility has an interest in DC distribution system. It has researched the LVDC system and has a plan to construct it for supplying DC power to customer directly. This research has drawn the economic feasibility analysis of LVDC distribution system for the utility. After that, the research has studied the design of LVDC system in consideration of Korean distribution power system environment and installed the LVDC test-lab. In addition, this paper presents construction plan of LVDC distribution system in Korea.

ECONOMIC FEASIBILITY ANALYSIS

If there are many DC customers and renewable energy sources in a certain area, utility might get economic benefit from the efficiency improvement in distribution network. However, Utility should find the application site for LVDC system because there were just few DC customers until now.

Numerous low loaded long-distance distribution lines are served by 22.9[kV] AC distribution lines in the Korean distribution network system. This is an unavoidable choice to compensate for the voltage drop.

Therefore, excessive cost is expended for the amount of electrical power load. Therefore, to replace the MVAC (Medium Voltage Alternative Current) distribution line with a LVDC distribution line is a solution for reducing excessive cost and providing better quality electricity to customer.

The distribution line for communication repeaters is one of the target models to replace with LVDC. This study performs economic evaluation for one of real distribution lines as shown Figure 1. This distribution system as shown Figure 1 has five customers of the communication repeater in the mountainous area where the total power demand is 35[kW] and the total distance of the line is approximately 1,600[m].

The economic difference between LVDC and MVAC with overhead line is analyzed with the NPV (Net Present Value) of 30 years. The idea of NPV takes into consideration that money spent or obtained in future periods will have a different value compared to money spent or obtained in the present. There are five items as Investment, Energy loss, Interruption & Outage, Fault repair, Maintenance costs to consider for economic feasibility evaluation. The NPV analysis method can express the present monetary value for all calculated costs and is given as:

$$NPV = C_{inv} + AIR \times [EBITDA \times (1-CTR) - DPC \times CTR] \qquad (1)$$

of present value; EBITDA: earnings before interest, taxes, depreciation and amortization; CTR: corporate tax rate; DPC: depreciation cost.

The result of NPV analysis for 30 years is shown as Table 1. It shows that the most economical method to install a distribution line for communication repeaters is the LVDC bipolar system. Therefore, it is an economical solution to replace MVAC with LVDC for the current power utility.

DESIGN OF LVDC DISTRIBUTION SYSTEM

Power utility needs to the design of LVDC distribution system for providing DC power to customer directly. It is necessary to select power supplying method, rated voltage, earthing and protection.

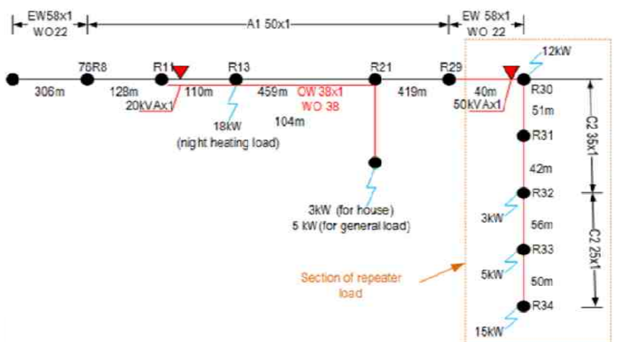

Figure 1. Schematic and information of the MVAC distribution line for communication repeaters

Table 1. NPV analysis for first year

Category	MVAC system	LVDC system	
		Bipole	Monopole
Investment Cost	92,982,685	92,804,536	89,638,916
Annual O&M Cost (EBITDA)	7,798,194	6,501,249	6,912,074
EBITDA*(1-CTR)	6,082,591	5,070,974	5,391,418
Depreciation cost (DPC) for 30 Yrs	3,099,423	3,093,485	2,987,964
DPC * CTR	681,873	680,567	657,352
EBITDA*(1-CTR)-DPC*CTR	5,400,718	4,390,407	4,734,066
Annual Installation Rate of Present Value (AIR)	12.41	12.41	12.41
O&M Cost (NPV)	67,017,734	54,480,747	58,745,216
Overall NPV	**160,000,419**	**147,285,283**	**148,384,133**

Supplying method and rated voltage

The basic system structures are unipolar and bipolar. The unipolar system has low investment costs. It is impossible to provide DC power to customer when fault occurs on the distribution line. However, the bipolar system has more reliable for supplying electricity. Although fault occurs on a pole, customers can receive DC power from the other pole. Therefore, power utility should select the bipolar system for LVDC distribution

IEC SEG4 is under discussion for standardization of LVDC distribution system. Referentially, IEC standard 60364 limits under 1,500[V] for the maximum DC low voltage. High voltage has advantages with power transmission capacity, losses and distance for power utility.

This study has analyzed the optimal rated voltage range using the method of technoeconomic application ranges idea. The analysis has used the Korea distribution system environment. The result of analysis shows the optimal voltage range as shown Figure 2. This case as shown figure was customer density of 50 customers per 1[km], interest rate 7[%] and load growth of 2[%] for the first five years. In conclusion, it is desired that power utility should select bipolar ± 750[V] system for LVDC distribution.

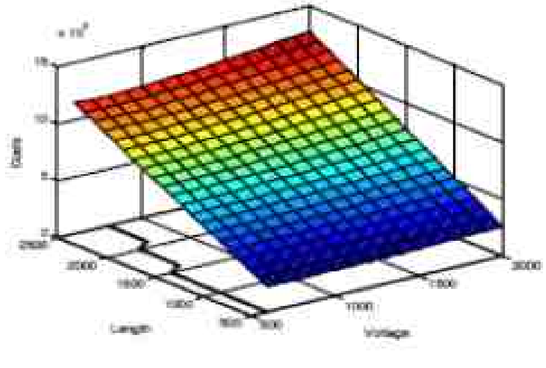

Figure 2. Cost levels for bipolar overhead line network in case of 3-phase customer connection

Earthing and protection

Eearthed (TN) and earth isolated (IT) system are main earthing system in LVDC. TN system has main advantage over protection coordination using high fault currents. However, TN system has serious corrosion problem form leakage DC currents and should maintain low earthing resistance for safety. On the other hand, IT system has low touch voltages from ground fault with the Korea distribution system environment as shown Figure 3 and an advantage over corrosion. As these reasons, it is expected to select the IT system for the LVDC distribution system of power utility.

Basically, two systems have circuit breakers against over currents and surge arresters against over voltage. In addition, the galvanic isolation between AD, DC and customer network is helpful to safety of LVDC distribution system. However, IT system needs to insulation monitoring devices (IMD) against double faults.

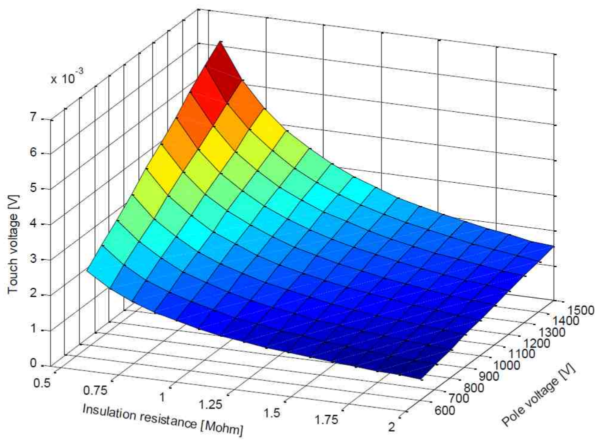

Figure 3. Touch voltage in earth isolated (IT) system

AC/DC Converter

Due to bipolar systems, customers can use 2-wire cables connected between positive and negative pole. As this reason, it can lead asymmetrical load conditions between DC output poles in system. In order to balance the output voltage caused by asymmetrical loads, a bipolar ± 750 Vdc distribution system has been configured by the conventional two line converters such as the 12-pulse thyristor based rectifier or the two-level AC-DC rectifier. These rectifiers have the simplest power stage which can be used in the LVDC distribution system. However, these types must need two separated AC-DC rectifiers with a three-winding transformer for bipolar transmission.

The three-level NPC AC-DC rectifier for bilateral power transmission has better power quality without additional transformers compared to the conventional methods. It can reduce current harmonics due to the multi-level operation and the AC-DC rectifier can offer the advantage of low voltage stresses on switches. However, the neutral-point voltage balancing problem, which is an inherent problem of three-level NPC AC-DC rectifier, restricts the development and application for bipolar ± 750 Vdc distribution systems. Without NP voltage balancing control, the harmonic components will greatly increase, and even the DC-link capacitors and the switching devices will probably be destroyed. If neutral-point voltage balancing problem could solve, the three-level NPC AC-DC rectifier will be an effective and practical solution for bipolar ± 750 Vdc distribution systems.

A variety of solutions have been introduced to balance the neutral-point voltage. For SPWM algorithm, the strategy to achieve neutral-point balance is by injecting appropriate zero-sequence signal to modulation signal. SVPWM methods alternatively select the positive and negative vectors in every switching cycle. However, these methods can work only in the case of perfectly balanced load. In addition, it would have difficulties to recover from load transients.

In this study, in order to improve the neutral-point voltage balancing of 3-level NPC rectifier for low voltage DC distribution, a practical control method was proposed. The proposed method is the mixed control algorithm. It composed of the digital balancing control which is an offset voltage control using SVPWM and the analog control method with an additional voltage balancing circuit. In addition, the proposed voltage balancing circuit can limit the short circuit current of the output side. This is an essential function in the practical DC distribution.

The simulation result for verifying the output of the unbalance compensation using the proposed voltage balancing circuit is shown as Figure 4. When a short-circuit occurred positive pole, the positive pole's output current is limited by the proposed voltage balancing circuit. During unbalanced load condition without voltage balancing operation, the difference between the output voltages is gradually increased. After the compensation algorithm is applied, the proposed circuit can control the output voltage to equilibrium.

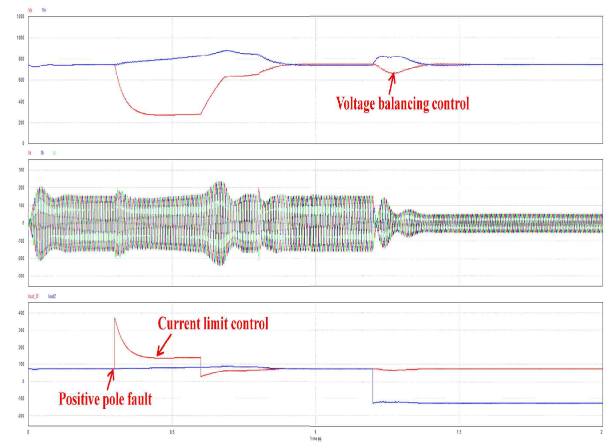

Figure 4. Simulation result of the proposed voltage balancing circuit

LVDC TEST-LAB

This study has constructed the LVDC test-lab to perform various hardware tests for applying LVDC distribution systems to the actual site as shown Figure 5. It has hardware simulators with battery, photovoltaic (PV) generator, AC and DC load, and DC lines. In addition, the short-circuit simulator was installed in LVDC test-lab. The 3-level Neutral-Point-Clamped (NPC) converter with the proposed voltage balancing circuit will be test in this test-lab before installation at actual field. Experiments of other devices for LVDC system will be performed in it.

In addition, the simulation model of the test-lab also has been developed using PSCAD/EMTDC to conduct the pre-simulation tests before conducting hardware tests and cross verification between the results of hardware.

Figure 5. LVDC test-lab for assessment of equipments

FUTURE PLAN

LVDC distribution system has great potential as the next power system. It has many advantages as efficiency, reliability, stability and controllability for power utilities. As these reasons, KEPCO have plans to research and develop the LVDC distribution system.

The first step of KEPCO is to build the LVDC distribution system at the actual distribution network. For this plan, the proposed 3-level NPC rectifier will be tested in LVDC test-lab. Then, the test-bed of LVDC distribution system will be constructed in Gochang PT (Power Testing) Center of KEPCO. This test-bed will be used for final field demonstration test for the project. One of the low loaded long-distance distribution lines from economic feasibility analysis will be the site of the project which is to construct the actual LVDC distribution system. This will be the stepping stone for expansion of DC distribution and DC microgrid by power utility.

CONCLUSION

Digital loads and renewable energy sources are increasing in power distribution network. The trend started from IDC, DC home and DC building demands to change the existing distribution system. It is expected that DC distribution system will supply many benefit to electric power utilities.

This paper explained the construction plan of LVDC distribution system in Korea. For this plan, this study has analyzed economic feasibility and designed the LVDC distribution system including AC/DC converter for electric power utility. After the construction of LVDC system for low loaded long- distance distribution line, it is expected to realize providing DC power to customer directly. In future, this project will spread to DC microgrid and extension business of DC distribution in urban area.

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