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A Study on the Application of DC HTS cable systems to enhance power transfer limits of a grid-connected offshore wind farm

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Abstract

This paper introduces two on-going projects for DC high temperature superconducting (HTS) cable systems in South Korea. This study proposes the application of DC HTS cable systems to enhance power transfer limits of a grid-connected offshore wind farm. In order to develop the superconducting DC transmission system model based on HTS power cables, the maximum transfer limits from offshore wind farm are estimated and the system marginal price (SMP) calculated through a Two-Step Power Transfer (TSPT) model based on PV analysis and DC-optimal power flow. The proposed TSPT model will be applied to 2022 KEPCO systems with offshore wind farms.

Key Words : Dc Hts Cable Systems, Offshore Wind Farm, Maximum Power Transfer, System Marginal Price, Two-Step Power Transfer (TSPT) Model

1. Introduction

South Korea will soon launch a 9 trillion won (US$7.8 billion) project to build the country's largest offshore wind farm with a total 2.5GW offshore wind farm by 2019 on the south-west coast region of Korea being considered. Following this offshore wind farm project, major concerns are implicated in finding ways to transfer the power into the power network. The development of high temperature superconducting (HTS) power cables is considered the most effective method to transfer the maximum power from offshore wind farms compared to conventional AC transmission systems. There are two on-going projects for DC HTS cable systems in South Korea. The first one is the Jeju project [1-3]. In this project, DC 80kV 250MW HTS cable systems have been developed since July 2011. The cable systems will be installed and operated within the Hanlim-Geumak Korea Electric Power Corporation (KEPCO) HVDC systems of Jeju Island in the latter half of 2014. The other is a Korea Electrotechnology Research Institute (KERI) project started in 2013, which develops and tests DC 250kV 2.5GW HTS cable systems. This paper proposes the

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application of DC HTS cable systems to enhance power transfer limits of a grid-connected offshore wind farm. In order to develop a superconducting DC transmission system model based on HTS power cables, the maximum transfer limits from offshore wind farm are estimated via PV analysis. In addition, the system marginal price (SMP) is calculated based on the principle of minimizing the system variable cost using DC-optimal power flow.

This paper is organized as follows. Section II discusses the DC HTS project in Korea. Section III discusses a Two-Step Power Transfer Model (TSPT). A case study of the 2022 KEPCO systems is presented in Section IV. Section V describes future work.

2. DC HTS Project in Korea

2.1 Jeju Project

In South Korea, an HTS cable project of power transmission levels, the Jeju Project, started in July 2011, with funding from the Korea government Ministry of Trade, Industry and Energy. This project is the first demonstration to apply a DC HTS cable system to actual power grids in South Korea.

Table 1. Specifications of DC HTS Cable [1]

Items	Values or type
Rated Voltage	DC 80kV
Rated Current	3,125A
Power Capacity	250MW/pole
Length	500m
Cable Configuration	1pole / 1cryostat
Insulation Type	Cold dielectric
HTS Wire	AMSC 344B, Ic > 80A
Temperature Range	67~72K
Operating Pressure	> 5bar G
BIL	285kV
Short Circuit Current	2kA / 1sec

LS Cable, Ltd. developed a DC 80kV HTS cable system under this project. Table 1 shows specifications of the DC HTS cable [1]. The DC 80kV, 250MW/pole HTS cable was installed through the Jeju power system in Korea, in parallel with the conventional cables of backup facilities, as shown in Fig. 1. The length is about 500m. The operation temperature is 67K to 72K.

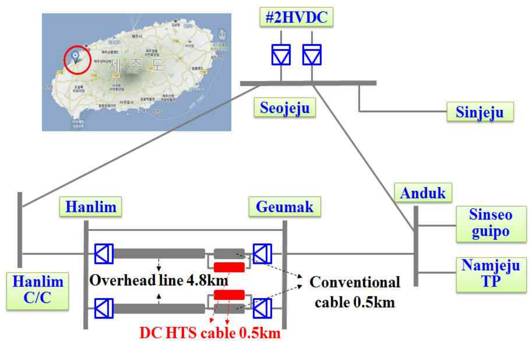


Fig. 1. One-line diagram of HVDC and HTS cable system in Jeju Island

The configuration of the DC HTS cable is illustrated in Fig. 2. The system had passed type tests and qualification tests in KEPCO Gochang Power Testing Fields [2-3].

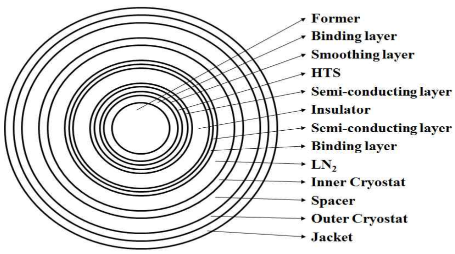


Fig. 2. Configuration of the DC 80kV HTS cable

Fig. 3 shows the test setup. Some power system studies show that the application of the DC HTS cable has little impact on the control of the high voltage DC (HVDC) system, and that there is no problem in the operation of the HTS cable and HVDC systems on Jeju Island [4]. KEPCO will operate the DC 80kV HTS cable system by the end of 2014, based on the results of tests and simulations.

Fig. 3. Test setup in KEPCO Gochang testing fields [2]

2.2 KERI Project

The Korea Electrotechnology Research Institute (KERI) has carried out a DC HTS cable project since 2013. The purpose of the project is the development of DC 250kV / 2.5GW HTS cable systems including termination and Stop Joint Box (SJB). Fig. 4 shows an example of the DC HTS cable system. The core is designed by the power system fault condition.

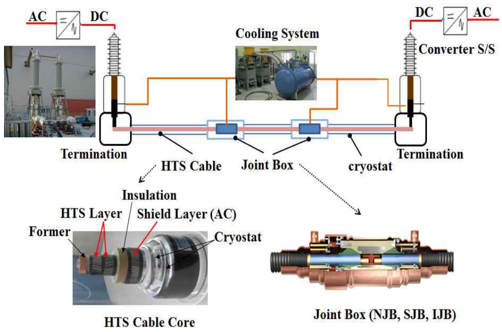


Fig. 4. Structure of DC 250kV HTS cable system

HTS layers are more than four layers because the rated current of the cable is DC 10kA. The insulation design is essentially based on that of the AC 154kV HTS cable in Korea. In this project, KERI also will construct a test facility for the DC 250kV / 2.5GW HTS cable system based on Electra 189. Fig. 5 shows the outline of the test system. KERI has a plan to test the developed DC HTS cable system using the test facility.

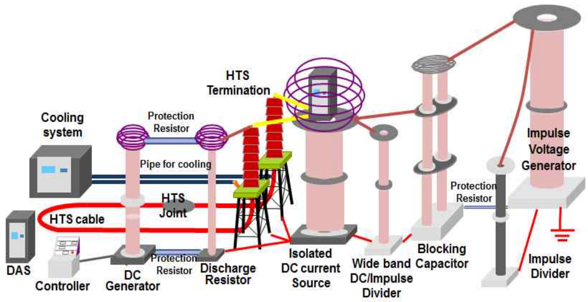


Fig. 5. Test facility for the DC HTS cable system

2.3 Large-scale Offshore Wind Farm in the South-west Coast

With the aim of becoming one of the top 3 powerhouses in offshore wind energy by 2019, the private and public sectors will invest a total of 9.2 trillion won to build a large-scale offshore wind farm with 2.9GW capacity on the southwest coast. KEPCO has carried out an offshore wind power project since 2011. Fig. 6 shows the roadmap of the project [5].

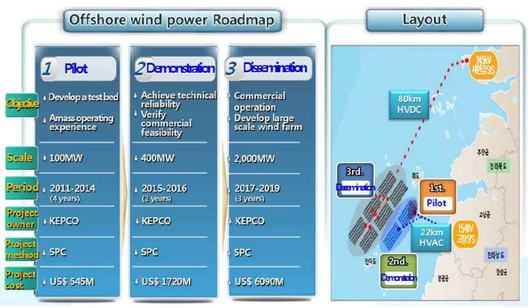


Fig. 6. Korea's offshore wind power roadmap

The roadmap of the project includes building a 2.9GW offshore wind farm in the west-southern sea area of Korea by 2019 and is scheduled to be constructed in 3 stages: 1) Pilot Stage (HVAC 500MW), 2) Demonstration Stage (HVAC 500MW), and 3) Dissemination Stage (HVDC 2GW).

2.4 Superconducting DC transmission system

The HVDC system takes AC electrical power from an offshore wind farm. It converts this power into high voltage direct current (DC) using an offshore platform mounted converter station. It then transmits the DC through a submarine cable to a land-based electrical network where it is converted back again to AC by another HVDC converter station. At the wind farm end of the link, a FACTS device such as STACOM is fitted to provide a reference AC voltage and dynamic reactive power support to the offshore grid. Both real and reactive power can be controlled. Fig. 7 shows offshore wind farms with 250kV, 2.5GW DC HTS cable system.

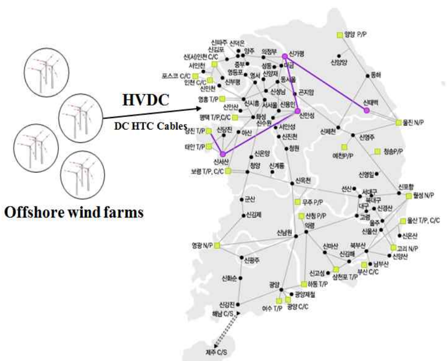


Fig. 7. Offshore wind farms with 250kV, 2.5GW DC HTS cable systems

3. Two-Step Power Transfer (TSPT) Model

Large offshore wind farms in the west-southern sea area of Korea by 2019 will be constructed and superconducting DC transmission system will be considered to interface with land. Power system operators and planners need to study power transfer from large offshore wind farms to enhance system reliability. In order to study power transfer enhancement of a grid-connected offshore wind farm with superconducting DC transmission system, this paper proposes a Two-Step Power Transfer (TSPT) model. Fig. 8 shows the calculation procedure of the maximum power transfer limits and system marginal prices. The procedure consists of two parts: Save a base case in Stage I and calculate maximum transfer limits and SMPs in Stage II.

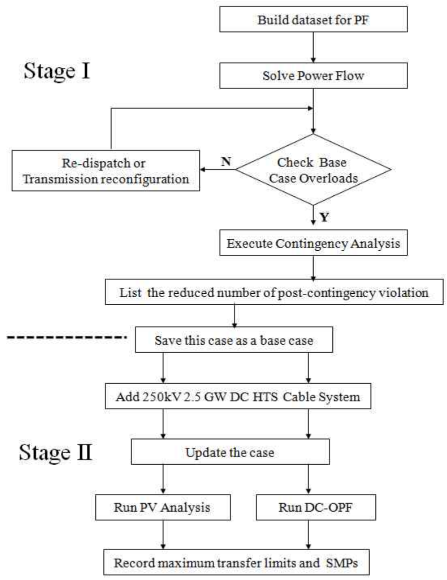


Fig. 8. Proposed TSPT model to evaluate power transfer limits

In the first stage, the power flow case for overloads over normal ratings are resolved and re-dispatch generating output is considered to clear all overloads of all transmission lines. The results were also examined to reduce the number of applied contingency violations. The modified dataset is saved as a base case for calculating maximum

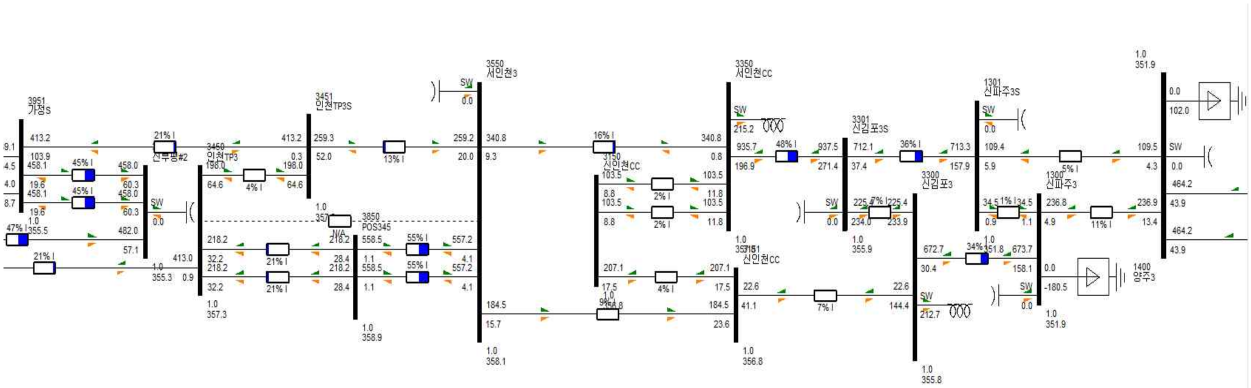


Fig. 9. KEPCO network topology near superconducting HTS systems

power transfer limits and SMPs and should have no base case overloads. In the second stage, a PV (Power-Voltage) analysis and DC-optimal power flow is run based upon the base case. Voltage stability is the ability of a power system to maintain acceptable voltage at all buses under normal operating conditions and after being subjected to a contingency. The PV analysis process involves using a series of power flow solutions for increasing transfers of MW and monitoring what happens to system voltages as a result. The relationship of voltage to MW transfer is non-linear, which requires full power flow solutions. At the “knee” of the PV curve, voltage drops rapidly with an increase in MW transfer. The power flow solution fails to converge beyond this limit, which is indicative of instability. Operation at or near the stability limit risks a large-scale blackout. Satisfactory operating conditions are ensured by allowing a sufficient power margin and the maximum power transfer limit is determined.

The current Korean electricity market is called a Cost-Based Pool, since the market price reflects actual generation costs. Under the pool system, all generators are obliged to submit the details of their production costs, which are independently checked and approved by the Generation Cost Assessment Committee (GCAC). Using this information, the Korea Power Exchange (KPX) prepares a price setting schedule and calculates the system marginal price (SMP) based on the principle of minimizing system variable costs. The System Marginal Price (SMP) is determined as the most expensive generation available for the trading period in the price setting schedule. After real-time dispatching, settlement for the energy produced takes place based on the market price (SMP, Capacity Payment)[6].

4. Case Study: 2020 KEPCO Systems

This study developed an analysis model of the 250kV, 2.5GW DC HTS cable system of KERI project through the proposed TSPT model. This paper presents the evaluation of the transfer limits from the offshore wind farm in the southwest seas of South Korea. In fact, there are still obstacles for the application of a submarine cable system based on the HTS technology such as the realization of a long distance cable and the cooling system. This study simulated a DC HTS cable system on the assumption that the cable system can overcome the obstacles. The length of the cable is about 80km as shown in Fig. 7. In order to develop the superconducting DC transmission system model based on HTS power cables, the maximum transfer limits from the offshore wind farm were estimated and the system marginal price (SMP) was calculated through a Two-Step Power Transfer (TSPT) model based on PV analysis and DC-optimal power flow. The proposed TSPT model will be applied to 2022 KEPCO systems with offshore wind farms. The following contingency lists are applied to 2022 KEPCO systems are as follows:

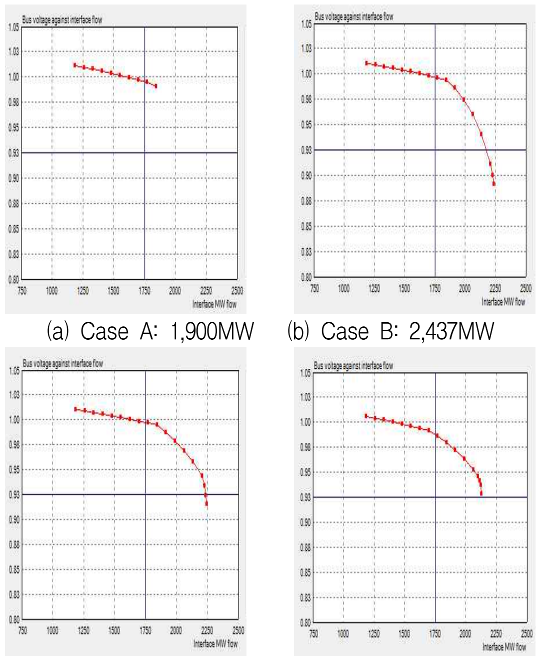
- Case A: ShinincheonCC (3151) - Seoincheon (3550)
  Seoincheon CC (3350) - Seoincheon (3550)
- Case B: POS345(3850) - Seoincheon (3550) 2ckt
- Case C: IncheonTP3S (3451) - Seoincheon (3550)
  Seoincheon CC (3350) - Seoincheon (355)
- Case D: Shinkimpo3S (3301) - Seoincheon CC(3350)
  Shinpajoo3S (1301) - Shinkimpo 3S(3301)

Table 2. Change of Power Flows with Contingencies

Line	Base	Case A	Case B	Case C	Case D
3550-3151	24%	-	21%	40%	22%
3550-3350	31%	-	29%	-	43%
3850-3550	26%	16%	-	12%	30%
1301-3301	16%	26%	18%	17%	-

Applying the contingencies to 2020 KEPCO systems, Table 2 shows the change of power flows of lines near connection points as shown in Fig. 9 as new generation resources from offshore wind farms are connected to the KEPCO power grids.

Fig. 10 shows the maximum power transfer limits using the proposed TSPT model. According to the contingency scenarios, maximum power transfer limits (2,743MW) based on PV analysis are determined compared to other contingency cases.

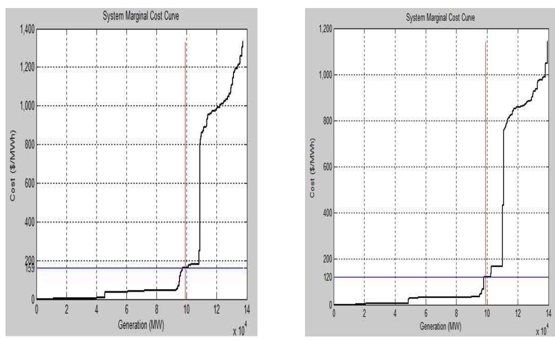


(a) Case A: 1,900MW (b) Case B: 2,437MW

(c) Case C: 2,157MW (d) Case D: 2,293MW

Fig. 10. Maximum power transfer limits through the proposed TSPT model

Increasing the supply of wind generating resources tends to lower the average price per unit of electricity because wind generating resources have very low marginal costs.



(a) SMP without WF (b) SMP with WF

Fig. 11. SMP calculation through the proposed TSPT model

Fig. 11 shows the results of system marginal prices with and without offshore wind farms, respectively. As shown in Fig. 11, the SMPs without and with offshore wind farms are around 150(won/kWh) and 120(won/kWh) respectively.

5. Conclusions

This study developed an analysis model of the 250kV, 2.5GW DC HTS cable system of the KERI project through a Two-Step Power Transfer (TSPT) model based on PV analysis and DC-optimal power flow. From the case study, superconducting DC systems contributed to maximizing power transfer limits from offshore wind farms and to reducing the system marginal price compared to the traditional AC transmission systems. The main results and contributions from this work are summarized as follows:

- Analysis model of DC HTS cable system was developed: Two Step Power Transfer (TSPT) model is proposed to evaluate power transfer model based on PV analysis and DC-OPF
- Application model for studying the price signal effect of offshore wind farm was proposed: From the case study, new generation resources such as wind power outputs can contribute to reducing the system marginal price

In the future, the developed application model will be applied to onshore wind farm analysis and then generation resources planning and transmission expansion planning with high wind power penetration will be studied.

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◇ 저자소개 ◇

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