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A study on Overvoltage and Protection of Line-Commutated Converter HVDC Metallic Return Cable

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Abstract: Metallic return cable in modern LCC HVDC system had been considered a necessary choice for newly installed projects, due to environmental concern near earth electrode. Like most of neutral cable that has been installed so far, it is unnecessary for those cables to require same specification to pole cable in the system. Usually, their voltage and current insulation limit is much lower than those of pole cables' requirement. To ensure reliable operation of HVDC system and to optimize neutral cable's insulating capability, further study on phenomena occurred on the neutral cable after fault on the system has to be measured and mitigated. In this paper, short circuit faults has been applied to LCC HVDC system, monitoring the effect on the neutral cable, and the counter measures to protect them are being considered.

Keywords: LCC HVDC, Metallic return cable, Neutral cable, Overvoltage and protection

1. INTRODUCTION

With enormous and rapid acceleration of Power semiconductor technology level, DC power related devices inherited from their development fairly directly. The most representative sate of the arts DC power applications is HVDC system for bulk power transmission. Because DC grid is asynchronous and have independent characteristic compare to AC grid, and yet they were interconnected together, many researches and experiments have been conducted concern to their mutual interference. Owing to the interactions between integrated AC system and DC part, the fault condition applied in the DC cable could make the entire system state suffers transient variation including harmful impact from the utility grid. For the stable operation with LCC(Line Commutated Converter) HVDC, especially, when many applications are including renewable energy sources, all of HVDC system's apparatus has to be stably composed, and the counter measures for fault conditions should be composed based on considering various system condition.

To complete line-commutated converter HVDC circuit, earth return path is necessary. Many of conventional LCC HVDC system use earth electrode as return path which simply flowing low voltage current into the ground located near or few kilometres away from the valve station. For HVDC system that interconnect island region or crossing the strait, submarine cable and sea electrode were commonly used. Those sea electrodes located on the sea floor have been facing challenges because of the environmental concerns made by dc current injected into the ocean, such as electric fields that inhibit the fish's navigation system or evoke corrosion on the nearby structures. To prevent problems related to electrode return path, some of the recently built HVDC systems adopted metallic return cable which connects each valve stations' low voltage points so that it does not connected directly to the sea floor. Because the metallic return cable compose unnecessary loop of electric circuit, the surge of fault current and voltage could circulate and damage the apparatus when fault has occur and propagate throughout the system, until they reach the ground side at the end of neutral cable. Thus, the failure of return cable electric system can be degenerated depends on whether the fault has occurred at rectifier side or inverter side.

In this paper, an electromagnetic transient model for LCC HVDC with 500kV, 3kA specification have been developed using PSCAD/EMTDC™. To measure metallic return cable overvoltage and overcurrent, 3 phase bypass circuit and AC/DC side fault has been implemented. Cable model is based on submarine cable equivalent parameter, surge arrester and capacitor for mitigate instant fault current and over voltage are located on the inverter side. The performance of this protection scheme is mainly focus on decreasing rate and magnitude of voltage and current for given situation.

2. METALLIC RETURN HVDC & CABLE FAULT

Swepol HVDC interconnection which were commissioned at 2000 by ABB was the first project that use metallic return. Since then, several projects install metallic return cable to

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Table 1. LCC HVDC using metallic return

Year	Project	Pole cable Rated voltage[kV]	Return cable Rated Voltage[kV]
2000	SwePol	450	20
2005	Neptune	500	20
2006	Basslink	400	20
2010	Storebaelt	400	20
2012	COMETA PJT	250	20
2013	Jindo-Jeju	250	24

avoid the use of earth or sea electrode. Voltage insulation level of metallic cable is quite different from those of pole cables because the voltage profile that they need to get through are the outputs from valve group's low voltage side. But for the return cable rated voltage that can be shown on the table I indicate that voltage level of return cable is around 20~24kV and has no proportional relationship with main pole cable's rated voltage level. Types of HVDC is not a dominant factor to influence the neutral cable insulation level, and it is quite clear, considering the fact that in normal operation, neutral cable of bipolar HVDC system have zero currents flowing. And during the abnormal operation with one pole cable out of service, it works exactly the same way how monopolar HVDC does.

For voltage source converter HVDC (VSC HVDC), on the other hand, no projects had ever been adopted neutral cable in their topology yet. It is mainly due to VSC valve group's operating characteristic which are consist of two pole level (+/-). '

To investigate transient overvoltage and overcurrent, IEC 61660 provides method for calculating short circuit currents in systems adjacent to DC applications. According to the approximation described in the IEC 61660, Steady state short circuit current and peak short circuit current are calculated using equation (1),(2) and (3)

$$I_{kD} = \lambda_D \frac{3\sqrt{2}}{\pi} \frac{U_N}{\sqrt{3} Z_N} \frac{U_{nTLV}}{U_{nTHV}} \quad (1)$$

$$\lambda_D = \sqrt{\frac{1 + (\frac{R_N}{X_N})^2}{1 + (\frac{R_N}{X_N})^2 (1 + \frac{2}{3} \frac{R_{DBr}}{R_N})^2}} \quad (2)$$

$$I_{pD} = k_D \cdot I_{kD} \quad (3)$$

Where k_D and φ_D is calculated below

$$k_D = 1 + \frac{2}{\pi} e^{-(\frac{\pi}{3} + \varphi_D)\cot\varphi_D} \cdot \sin\varphi_D (\frac{\pi}{2} - \tan^{-1}\frac{L_{DBr}}{L_N}) \quad (4)$$

$$\varphi_D = \tan^{-1} \frac{1}{\frac{R_N}{X_N}(1 + \frac{2}{3}\frac{R_{DBr}}{R_N})} \quad (5)$$

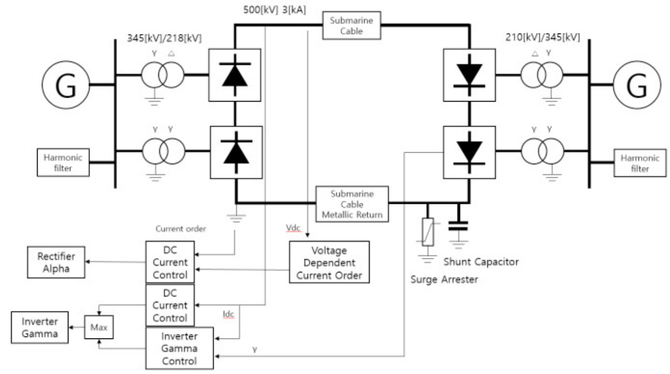

Fig.1. HVDC circuit and control diagram

From the equation, U_N and Z_N is AC network voltage and equivalent impedance for each, which clearly influence the short circuit level of the target system.

2. SIMULATION SYSTEM DESCRIPTION

A system model that have been developed are depicted in Fig.1. AC grid is 345kV with relatively high stability, since this paper is mainly focus on neutral cable transient phenomena and not consider grid's SCR value. To alleviate dc harmonic, 12 pulse valve groups are considered, each of them are connected to AC grid by transformer that have 345/218[kV] tap ratio on the rectifier side and 345/210[kV] on the inverter side. 11^{th} and 13^{th} harmonic filters are attached on each side for harmonic distortion from the DC to AC side. Converter rated values are 500kV/3kA, and steady state firing angle of each valve is 20/140 degrees.

To maintain rated value and inverter gamma value as low as possible for better operating effeciency, 3 PI controllers give orders to thyristors on rectifiers and inverters. In order to minimize gamma values, controller select more dominant values between two control signals for inverter gamma order. Voltage dependent current order and Inverter DC current order are both related to fast recovery of HVDC system during and after the fault and their controller gain values needs to be relevant to prevent additional commutation failure.

Table 2. Cable Parameter

2 Bundle	R [Ohm]	L [H]	C[uF]
Pole Cable	0.15	0.035	18.9
Neutral Cable	0.2	0.035	26.2

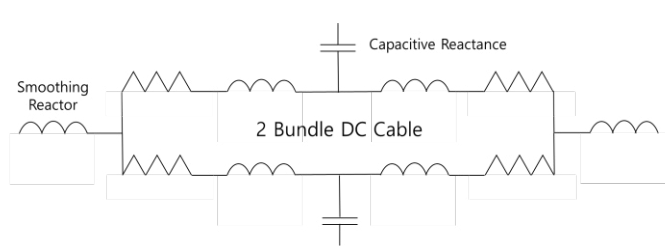

Fig.2. Two bundle DC cable configurations for simulation