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향후 DC 전력 계통에서의 자려 공진 DC 차단기에 관한 연구

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Study of Self-excited Resonant DC Circuit Breaker in Future DC Grid

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Abstract – With the increasing utilization of high-voltage, direct current (HVDC) transmissions in modern power systems, the DC grid is becoming a hot topic in academic and practical systems. In the DC grid, one of the urgent problems is the fast clearance of the DC fault in the DC network. One preferred method is to isolate the faulty point from the DC network in a short time. The DC circuit breaker is to interrupt the overcurrent after DC faults occur. In this paper, a self-excited resonant DC circuit breaker is an easy and cheap equipment to interrupt the DC fault current. The Mayr's arc model is utilized to simulate the self-excited DC circuit breaker in a DC test system in PSCAD/EMTDC.

1. Introduction

With the emerging growth of high voltage direct current (HVDC) links in modern power systems, the multiterminal HVDC system and DC grid are becoming attractive in recent years [1]. Two main types of converter are widely utilized in HVDC systems: current-source converters (CSC) with thyristors and voltage-source converters (VSC) with insulated-gate bipolar transistors (IGBT). Due to its congenital deficiencies in control strategy, the CSC-HVDC system has difficulties in the utilization of future DC grid [2].

Compared to conventional CSCs, the self-commutated VSCs are more flexible. The VSC-HVDC allows controlling active and reactive power independently, does not need AC filters, and has the black start capability [3]. Modular multilevel converter (MMC) is a major forward step for VSC technology [4]. DC grids would be more efficient at connecting remote sources of renewable energy. In China, one three terminal and one five terminal VSC-HVDC projects have been put into service in 2014 [5], [6].

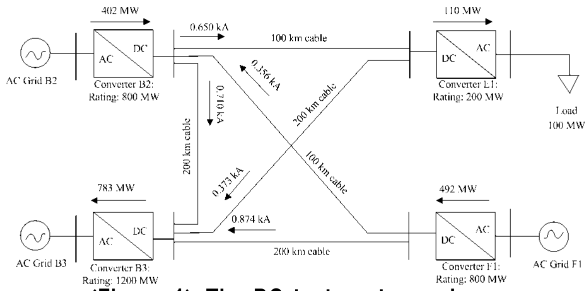
The DC circuit breaker is preferred after DC faults in the DC network. DC circuit breakers with solid semiconductors have fast and effective interruption; however, they are very expensive and cause power losses during normal operation. The self-excited DC resonant circuit breaker is simple in control and the investment is low.

This paper gives the simulation of a DC test system with the self-excited resonance DC circuit breaker. The electromagnetic transients program PSCAD/EMTDC is used to perform the simulation.

2. A DC Grid Test System and DC Circuit Breaker

2.1 A DC Grid Test System

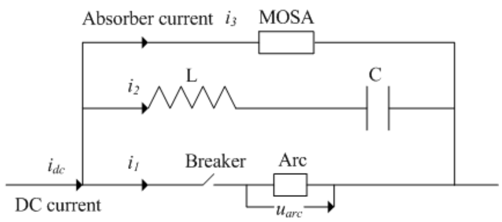
The CIGRE B4 DC grid test system was implemented to study the effect of the HVDC circuit breaker. The four-terminal VSC-HVDC system, i.e. DCS2 model, was modified into a DC test grid, as shown in Fig. 1 . The converters in the DC test system are half-bridge sub-module MMC and the vector control strategy was applied in the converters. The power-flow of the DC network and the cable length are shown in Fig. 1. The DC voltage of the cable is ± 200 kV.



<Figure 1> The DC test system scheme

2.2 Resonant DC Circuit Breaker

The HVDC circuit breaker is different with AC circuit breaker. The AC circuit breaker has to wait for the zero crossing point and works to interrupt fault current. In the HVDC transmission line, due to the absence of current zero crossing, the HVDC circuit breaker must have the ability to interrupt the current once a fault occurs. The self-excited resonance DC circuit breaker is one option to interrupt DC current, The scheme of the DC circuit breaker is shown in Fig. 2. The AC breaker in the main branch could be a SF6 gas circuit breaker.



<Figure 2> The self-excited DC resonant circuit breaker

From the Fig. 2, it is not difficult to write the equations below,

$$L\frac{d^2 i_2}{dt^2}+\frac{du_{arc}}{di_1}\frac{di_1}{dt}+\frac{1}{C}i_2=0 \tag{1}$$

$$i_1=i_{dc}-i_2 \tag{2}$$

from (1) and (2), the current on the AC circuit breaker is given as

$$i_1=i_{dc}\left[1+e^{-\left(\frac{L}{2}\right)\left(\frac{du_{arc}}{di_1}\right)}\cdot\sin(\omega t)\right] \tag{3}$$

In the (3),the gradient du_{arc}/di_1 of the arc voltage against the rising current is negative; The larger the value $\left|du_{arc}/di_1\right|$, the more rapidly the self-excited oscillatory current grows. From (3), the inductance in the LC branch could not be very large.

2.3 Metal Oxide Surge Arrester and Arc Models

The surge arrester is to suppress the overvoltage on the hybrid circuit breaker and absorb the energy during the fault. The arrester can be a metal oxide surge arrester (MOSA) and is modeled as a nonlinear resistor.

The arc models in the SF6 circuit breaker have been studied in [8]. The Mayr's model is shown in (4), and the Cassie's model is shown in (5), and the Schavemaker's model is shown in (6).

$$\frac{1}{g}\frac{dg}{dt}=\frac{1}{\tau}\left(\frac{u_{arc}\cdot i_{arc}}{P_o}-1\right) \quad (4)$$

$$\frac{1}{g}\frac{dg}{dt}=\frac{1}{\tau}\left(\frac{u_{arc}^2}{u_c^2}-1\right) \quad (5)$$

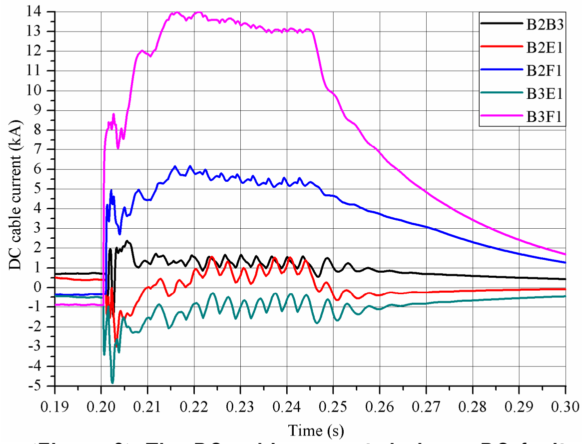
$$\frac{1}{g}\frac{dg}{dt}=\frac{1}{\tau}\left(\frac{u_{arc}\cdot i_{arc}}{\max(U_{arc}|i_{arc}|, P_o+P_1\cdot u_{arc}\cdot i_{arc})}-1\right) \quad (6)$$

where g is the arc conductance; τ is the time constant; u_{arc} is the voltage across the arc; i_{arc} is the current through the arc; u_c is the constant arc voltage; P_o is the cooling constant in Watt; P_1 is the cooling constant; U_{arc} is the constant arc voltage in the high current area.

3. Case Study and Simulation Verification

3.1 The DC Grid Test System Simulation

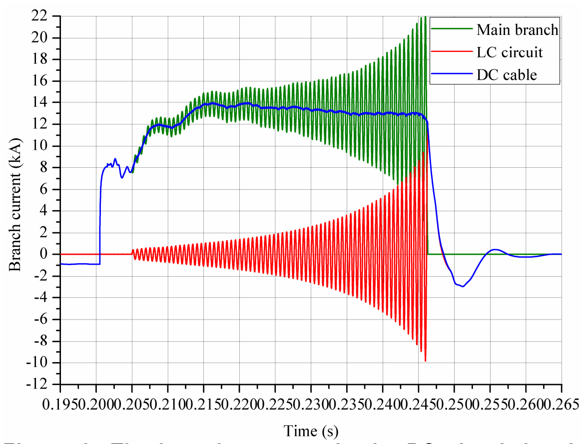
The DC test system is a four-terminal HVDC network with five transmission cables. In the DC test system, the total simulation time is 0.3s with a time step of 1.0us. A line-to-line fault was performed at the middle of the cable B3F1. The DC currents response in different DC cables are shown in Fig. 3. It is clear to see that the DC current on the cable B3F1 increases from -0.874kA to 14kA within 15ms.



<Figure 3> The DC cable current during a DC fault

3.2 DC Circuit Breaker Simulation Verifications

The DC resonant circuit breaker was installed in the DC cable nearby the B3 converter. The DC circuit breaker started to operate at 0.205ms after the detection of the increasing DC current on the cable B3F1. In the DC circuit breaker in Fig. 2, the Mayr's arc model are utilized, where τ is 0.3us and P_o is 10,000kW.



<Figure 4> The branch currents in the DC circuit breaker

The growing oscillation current on the LC branch increased from zero, as shown in the red curve in Fig. 4. Meanwhile, the AC circuit breaker branch has an oscillation current, as shown in the green curve. When the current through the AC breaker has a zero crossing point at about 0.246ms, the AC breaker operate to interrupt the oscillation current through the AC breaker. The current on the cable is totally cleared at 0.260ms because the energies stored in the inductance L and capacitor C could cause oscillation in the cable.

4. Conclusions

This paper presents a possible DC test system in the future power system. The DC cable current increases very rapid after a DC fault occur, and the overcurrent in the network is very serious. The DC faulty point need to be isolated in a very short time.

In the DC test system, the self-excited resonant circuit breaker is utilized to isolate the DC fault. The self-excited resonant circuit breaker comprises one AC breaker path, one LC branch and one MOSA. After the detection of the DC fault, the oscillation currents start to increase in the DC circuit breaker. When the current through the AC breaker reaches to the zero crossing point, the AC breaker is opened. The resonant DC circuit breaker is easy to put into real HVDC system or DC grid and the cost is not high.

However, the self-excited resonant DC circuit breaker has its inherent disadvantage. In the operation, the AC breaker has to wait for the zero crossing point. Thus, the response of the resonant DC circuit breaker is fast. Another disadvantage is the maximum current on the AC breaker, the maximum current on the AC breaker is about two times of the cable current. After the current interruption of the AC breaker, the energy stored in the LC path maybe cause oscillation in the DC network.

Future works about other topology of DC circuit breaker are considered.

Acknowledgement

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[Reference]

[1] C. M. Franck, "HVDC circuit breakers: a review identifying future research needs," IEEE Trans. Power Del., vol. 26, no. 2, pp. 998-1007, Apr. 2011.

[2] H. J. Lee, G. T. Son, J. I. Yoo, and J. W. Park, "Effect of a SFCL on commutation failure in a HVDC system," IEEE Trans. Appl. Supercon., vol. 23, no. 3, Jun. 2013.

[3] M. Barnes and A. Beddard, "Voltage source converter HVDC links- the state of the art and issues going forward," Energy Procedia, vol. 24, pp. 108-122, 2012.

[4] J. Dorn, H. Gambach, J. Strauss, T. Werterweller, and J. Alligan, "Trans Bay Cable - A breakthrough of VSC multilevel converters in HVDC transmission," CIGRE Colloquium 2012, San Francisco, 2012.

[5] X. Li, Z. Yuan, J. Fu, Y. Wang, T. Liu, and Z. Zhu, "Nanao multi-terminal VSC-HVDC project for integrating large-scale wind generation," in IEEE Power & Energy Society General Meeting 2014,Washington, 2014.

[6] J. Hu, C. Zhao, X. Zhang, and X. Yang, "Simulation study of the Zhoushan project as a three-terminal DC transmission system," in IEEE Power & Energy Society General Meeting 2012, San Diego, 2012.

[7] H. Nakao, Y. Nakagoshi, M. Hatano, and T. Koshizuka, "D.C. current interruption in HVDC SF6 gas MRTB by means of self-excited oscillation superimposition," IEEE Trans. Power Del., vol. 16, no. 4, pp. 687 - 693, Oct. 2001.

[8] P. H. Schavemaker and L. van der Sluis, "An improved Mayr-type Arc model based on current-zero measurements," IEEE Tran. Power Del., vol. 15, pp. 580 - 584, Apr. 2000