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Effect of Superconducting Fault Current Limiter (SFCL) on HVDC Circuit Breaker

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ABSTRACT

In HVDC systems, the used of HVDC circuit breakers have shown successful results. But fault current level has a serious problem in HVDC system because during dc fault interruption Natural zero current is not possible. So artificial zero crossing DC fault current should be somewhat modified with DC current breaking topology. By combining fault current limiter with dc current breaking topology (using black box arc model) is an alternative feasible solution. This paper gives review of application of resistive super conducting fault current (SFCL) for DC circuit breaker (mechanical CB) with DC current breaking topology to estimate the effects of combining fault current limiter on MCB to verify its DC fault current interruption characteristic.

Keywords : HVDC, Superconducting Fault Current Limiter, DC Circuit Breaker, Current Interruption

I. INTRODUCTION

Recently, the interest in high voltage direct current (HVDC) multi-terminal systems has been increased. The industrial growth of a nation requires increased demand and consumption of electrical energy. This has led to increase in the generation of electrical energy and transmission facilities which bridges very long distance with low losses to meet the demand [6]. The voltage levels increase is not always possible. In case of AC system, the most of problem occurs due to long distance transmission because of that loss increases as per distance increases. Point to point HVDC system can overcome this problem. This development has led in DC transmission. The reliability of DC transmission systems is good as compare to AC system. Particular, the voltage-source converter (VSC) based HVDC system is now available. It is a better alternative than conventional thyristor-based HVDC systems; particularly in developing multi-terminal HVDC systems (MTDC).

Multi- terminal HVDC systems have some advantages: MTDC system is more flexible for interconnection, economical than two terminal DC links, each terminal operate at different current and power and number of terminal require less which reduces cost and losses. Reliability, controllability and efficiency strongly depend upon the HVDC circuit breakers. The absence of dc circuit breaker is the key obstacle in HVDC point to point system [3]. DC circuit breakers isolate the faulty line quickly by breaking dc fault current with using different dc fault current interruption method. Because natural zero current is not possible. For that artificial current zero should be somewhat modified. A forced current reduction method can be used. But energy dissipation during DC fault interruption is still lacking Combine fault current limiter with dc circuit breaker is a one feasible solution.

To overcome high fault current, many type of current limiting device is used but superconducting fault current limiter is a most effective solution. Superconducting fault current limiter (SFCL) is an effective device which used superconductors to limit or reduce unanticipated electrical surges or high level fault current that may occur on distribution as well as transmission networks. There is different type of SFCL (saturated iron core, inductive and resistive) but resistive SFCL is quite good than other type of SFCL to reduce the fault current level during fault and help to improving the performance of HVDC circuit breaker. This is connected in series to system. Resistive SFCL are usually designed by high temperature superconductor (HTS). In expanding the power grid they play an important role than low temperature superconductor which is used in saturated iron core [2]. In this, DC resistive SFCL is used.

The main aim of this paper is to study the breaking topology used (black box arc model) for mechanical circuit breaker and Effect of with and without Resistive SFCL with DC circuit breaker (Mechanical) compare from its current interruption characteristics.

II. SYSTEM DESCRIPTION

Figure 1. described the simple ±100 KV symmetrical, monopole, point to point, two-level, half bridge HVDC system. To analyse the effect of SFCL on HVDC circuit breaker (mechanical CB), VSC HVDC test bed model designed in MATLAB/SIMULINK [1].

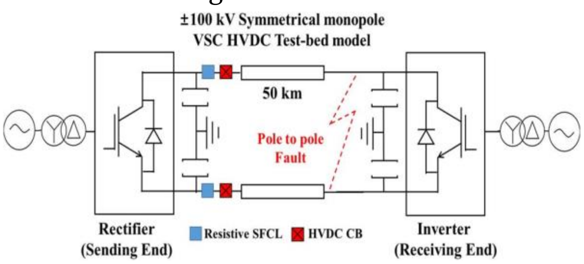

Figure 1. Two level point to point HVDC test-bed model

HVDC transmission system designed with two terminals. It is called converter stations. Rectifier as sending end which convert alternating current (AC) into direct current (DC) and inverter as receiving end which convert DC into AC. This HVDC system is adjacent to the AC link. Star – delta transformer is connected to sending and receiving end for conversion purpose (step down the voltage) and the neutral available on the primary side is earthed to avoid distortion. A phase reactor (L_p) added between transformer and converter on both side to decrease harmonic voltage and current in dc line. Resistive SFCL and HVDC circuit breaker located on receiving end of rectifier. By considering DC fault (pole to pole or line to line) on this system before inverter. This fault considered as a most severe in case of HVDC system. The HVDC link substituted equivalent RL impedance, which enable the X/R ratio of the power system to be determined. In the area of power semiconductor devices, adaptive control strategies and DC protection equipment many technological development increased. This is more beneficial in the pace of application of DC transmission system [9]. This help to reduce the cost of converter station by reducing its component and also help in improving system performance with reliability. In VSC based technology the basic element is insulated gate bipolar transistors (IGBTs). IGBT based VSC advantages than thyristor based current source converter (CSC) system. Thyristor are only turn on device but IGBT is advance power semiconductor device [9]. This transmits active power and can provide the required amount of reactive power at both power sending and receiving end.

Generally the DC component makes the symmetrical current become asymmetrical. If higher the X/R ratio of a circuit, longer time constant will take DC component because this ratio affect the DC component. This HVDC system utilized to concentrate the interruption performance of dc fault current. Detailed specifications of the HVDC link are as follows: the rated voltage =±100 kV, nominal current = 1 kA, nominal power flow =100 MW and the transmission line length = 50 km [1].

III. BASIC WORKING OF BREAKER

A circuit breaker is equipment which can open or close a circuit under no load, full load and fault condition. In case of abnormal condition, the main function of a circuit breaker is to isolate the faulty part of the power system. A relay detects faulty part of system and after tripping of circuit signal sends to the circuit breaker. CB receives the trip signal from relay and CB protects the faulty part of power system from healthy part. It has two contacts that are fixed and moving. Under normal operating condition, the contact of CB remains closed position. After occurrence of fault on system, the moving contact of CB moves to interrupt the circuit. After separation of contact shown in figure 2 [7], the flow of current is interrupted, because of that arc is struck between them. For extinguishes the arc, liquid or gas used as an insulating medium.

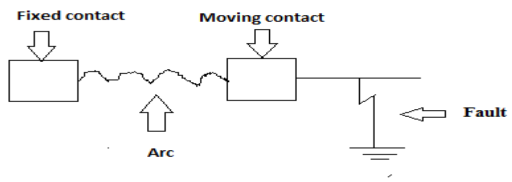

Figure 2. Contact separation of circuit breaker

The DC breaker have fulfil the following basic requirement

- ✓ To interrupt the current have to create a current zero crossing
- ✓ Dissipate the energy stored in the inductance of system
- ✓ After current interruption , withstand the voltage response of the network

IV. MODELLING OF ARC FOR MECHANICAL CIRCUIT BREAKER

ARC SWITCHING OF CIRCUIT BREAKER

For better understanding of the current interruption process in HVDC CB arc model were developed. The arc model simulates the strongly non linear behaviour of the circuit breaker arc. A very small time constant of CB arc of because it's non linear behaviour CB. After occurrence of fault, fault current flows through the arc channel between the contacts of breaker. The current causes a voltage across the CB contact because of non -zero resistance is called arc voltage. Behaviour of arc between contacts of CB is work as a non-linear resistance. Thus, zero crossing of arc voltage and current at same time instant. The CB can interrupt the fault current, if the arc between contacts of breaker is cooled sufficiently and it is possible only at the time the current goes through zero, because the electrical power input which flows into the arc channel is zero.

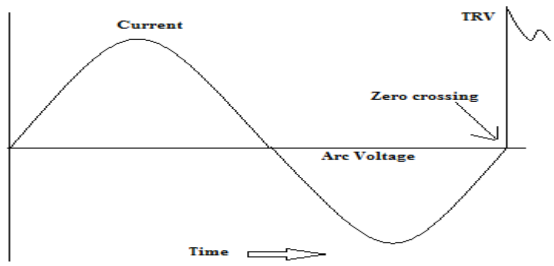

Figure 3. Arc voltage and current when contact separation

During interruption of current, the arc resistance increases from zero to almost infinite in only microseconds. Immediately after current interruption, the transient recovery voltage (TRV) builds up across the contact of CB as shown in figure 3 [8]. As the hot gas mixture in the interrupting chamber does not change to a complete insulating state instantaneously, the arc resistance is finite and a small current can still flow: the post-arc current [8]. In mechanical CB the implantation of arc dynamic is a major concern in the design for an accurate simulation model.

BLACK BOX ARC MODELLING

Black box arc model are used to simulate the arc dynamic behaviour by calculating the arc conductance by using differential equation [1] as shown in following

$$\frac{1}{g}\frac{d_g}{dt} = \frac{1}{\tau(g)}\left(\frac{ui}{Pc(g)} - 1\right) \qquad (1)$$

Black box arc model describes the electrical behaviour of the CB because it is mathematical description of the electrical properties of arc. For the differential equation, measured voltage and current are used. Mayr and cassie model considered as a black box arc model. These models based on energy balance equation and energy balance theory is used for zero interruption of the arc and also called Cassie's theory. After current zero, some gas ionised between space contain contacts of CB, that time it has a finite post-zero resistance. Because restriking voltage is zero, power is zero at moment of the current zero. Power again becomes zero, when the arc is finally extinguished. The gap is fully de-ionised and its resistance is infinitely high [7].

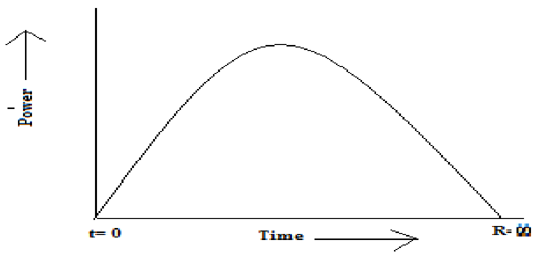

Figure 4. Energy balance theory

First the power in increased and then finally reaches zero value as shown in Figure 4. [6] In between these two limit. Energy is generated in CB contact space due to increase of restriking voltage and current. The energy appears in the form of heat. This generated heat remove as early as possible for that CB is designed by cooling the gap, giving a blast of air or flow of oil at high velocity and pressure. The arc extinguished if the rate of removal of heat is faster than the rate of heat generation. If it happened opposite then space break down and arc transfer for another half cycle.

Black box arc model only consider for the continuous model environment. To implement continuous model into discrete model, due to complicated nature of the system, transformed into integral form as following. It is implanted in modified model as shown in figure 5. [1]

$$g = \int_0^t \frac{1}{\tau}\left(\frac{i^2}{Pc(g)} - g\right) dt \qquad (2)$$

Where,

- g – arc conductance
- $Pc(g)$ – arc cooling power
- τ- arc time constant

Arc conductance depends upon arc resistance of CB. High resistance interruption method is used for arc interruption for DC CB. In this method, its resistance is increased so as to reduce the current to an insufficient value to maintain the arc. Then arc resistance can be increase by cooling, lengthening and splitting the arc. Energy associated with its magnetic field appears in the form of electrostatic energy, when current is interrupted [7]. Then high voltage (arc voltage) appears across the contact of CB. This phenomenon is used for MCB. For calculating $Pc(g)$ and arc time constant following equation is used [1]

$$Pc(g) = \rho.P_{0.g^a} \qquad (3)$$

$$\tau(g) = \tau_{0.g^b} \qquad (4)$$

Where,

- P_0 – constant cooling power factor
- P – blow pressure
- a, b – free parameter

*P*0 is the constant cooling power factor which depends linearly on the blow pressure *p*. Parameter of designed black box arc model are shown in following table[1]. This is used for equation (3) and (4)

Table1. Parameter of designed black box arc model

Parameter	Value
Po	0.393 MW
p	70bar
a	0.25
To	15 micro sec
b	0.5

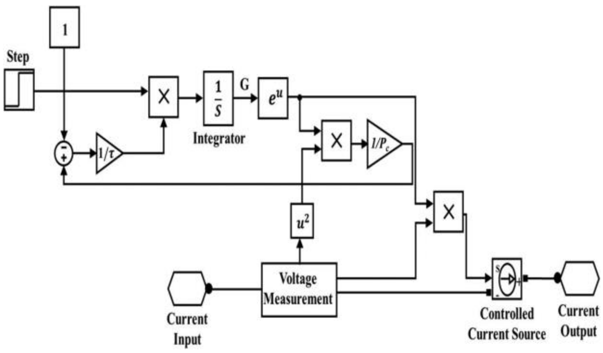

Figure 5. Modified Mayr black-box arc model designed using MATLAB/SIMULINK for a discrete simulation environment

Figure 3 the modified Mayr black-box arc model use for MCB, which assumes Arc conductance, g, arc cooling power, $Pc(g)$ and arc time constant, τ. The advantage of the modified Mayr arc model is that it is able to determine the breaking capability of MCB by controlling $P_C(g)$. [1]

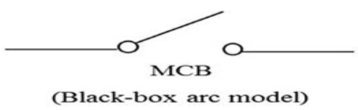

Figure 6. Mechanical circuit breaker

In case of MCB as shown in figure 6 [1], a DC current is reduced by increasing the arc voltage to higher value than that of the system voltage. If the arc path is purely resistive, then the arc voltage is in phase with the arc current.

V. SUPERCONDUCTING FAULT CURRENT LIMITER

In DC systems voltage/current switching stress, which is aggravated by large fault current, might damage DC circuit breaker this problem can be simply solved by applying a SFCL. SFCL is an effective device for limiting current when properly designed and placed in proper positions in an electrical grid. It is able to limit short-circuit current I_{SC} to values compatible with reliability and safety of the installed network components. SFCL based on a phenomenon of superconductivity and used a superconductor which is inter- metallic alloy or compound and. It conducts electric power without negligible resistance below a certain temperature. The current limiting behaviour of SFCL depends on their non- linear response to temperature, current and magnetic field variations. If any of this parameter increases it can cause a transition between the superconducting state and the normal conducting state [4].

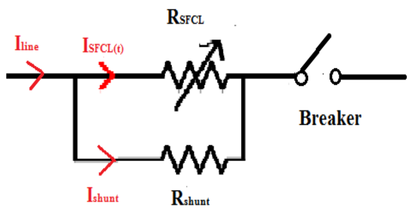

Figure 7. Simple circuit of resistive SFCL

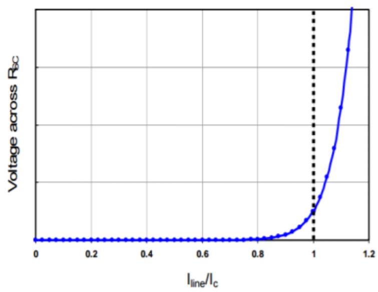

Figure 8. Voltage across Rs and I

Resistive SFCL is based on quenching phenomena of super-conductor. Figure 7. shows the simple circuit of resistive SFCL [5]. It uses the superconducting material as the main current carrying conductor under normal operation of grid. Resistive type SFCL generally connected in series with system before breaker. Figure 8. [4] shows the graph of voltage across RSFCL as a function of the ratio of current through the device, I_{line} to the "critical current", I_C, of the superconducting element Resistive SFCL are usually designed by HTS. HTS are the substances that lose all resistance below temperature attainable only by liquid nitrogen at 77k. When current in normal position, that time superconductor is in a superconducting state with negligible resistance. After occurrence of fault on system, the current increases than its critical current, that time superconductor goes into its normal state from its superconducting state and the current level at which the quench occurs is determined by the operating temperature, and the amount and type of superconductor. When resistance increase in fast, it produces voltage across superconductor. It causes to transfer the current directly to shunts, which are a combined inductor and resistor. The shunt limits the voltage increase across the superconductor during a quench. The superconductor acts like a switch that initiates the transition of the load current to the shunt impedance $(R_{shunt/L_{shunt}})$with millisecond response. Ideally, the fault current is limited within first cycle of fault current. R_{shunt} is a parallel resistance or inductance connected with superconducting element to avoid non-uniform heating of the superconductor during the quench to adjust the limiting current and to avoid over-voltages due to the fast current limitations. Output of this SFCL is connected to input of CB.

VI. DISCUSSION

In figure 9 shown the current interruption characteristics of the mechanical CB with time and gives the DC fault interruption performance of the MCB.

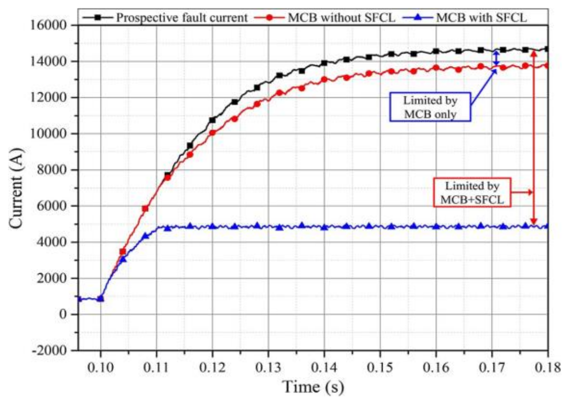

Figure 9. Interruption characteristics of the MCB when SFCL was applied

Fault was generated at receiving end at t= 0.1 sec. without SFCL, maximum fault current was 14.7KA and after connecting the MCB a current reduced from 14.7KA TO 13.8 KA. In case of with SFCL, a current reduction from 14.7 to 4.8 KA means 67.3% reduction of current [1].

VII. CONCLUSIONS

This paper gives an overview of breaking topology used for mechanical circuit breaker (MCB) and resistive SFCL. New DC breaking topology used for DC CB to determine the breaking capability of MCB by controlling arc cooling power $Pc(g)$ that is modified black box arc modeling. The effect of with and without SFCL on HVDC circuit breaker and how much current can be control from its current and time interruption characteristics as a proposed in this study. Resistive SFCL is the best solution for HVDC CB to minimize its fault current level rather than other current limiting devices.

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