DEVELOPMENT OF HIGH SPEED DC CIRCUIT BREAKER USING IGBT DRIVERS

HongJoo Kim
KEPCO – Republic of Korea
Hongjoo.kim@kepco.co.kr

YoungPyo Cho
KEPCO – Republic of Korea
yp.zo@kepco.co.kr

YoungPyo Cho
KEPCO – Republic of Korea
hm.kim@kepco.co.kr

JinTae Cho
KEPCO – Republic of Korea
jintaecho@kepco.co.kr

JuYoung Kim
KEPCO – Republic of Korea
juyong.kim@kepco.co.kr

InYong Seo
KEPCO – Republic of Korea
Inyong.seo@kepco.co.kr

ABSTRACT

For high speed DC circuit breaker, this paper proposes two type which is semiconductor type circuit breaker and hybrid type circuit breaker. Semiconductor type circuit breaker consist of two IGBT divers and one Surge Arrester(SA). Hybrid type circuit breaker consists of one mechanical fast switch and two IGBT drivers and on SA. These three components are composed of parallel circuits. Three prototype(once semiconductor type and two hybrid type) are manufactured and installed at LVDC(+/−750Vdc) demonstration site which is in Gochang Power Testing Center of KEPCO Research Institute. Fault tests are performed by AFG(Artificial Fault Generator) and the results, analysis and conclusion are finally presented in this paper.

INTRODUCTION

Recently, DC(Direct Current) loads such as data center, electric vehicle station, DC home appliance and DC sources such as Energy Storage System(ESS), Photovoltaic(PV) are increasing in power distribution system. LVDC(Low Voltage Direct Current) distribution system technology is getting attention as a solution of increasing conversion efficiency and hosting capacity for these facilities. KEPCO(Korea Electric Power Corporation) has researching LVDC distribution system and demonstrated DC microgrid in an island currently. To expand LVDC business, it is positively necessary to ensure stability and reliability of the LVDC grid. DC grid protection scheme and standard is unorganized compared with AC grid. And research of circuit breaker for LVDC is in early development stage. In conventional protection method, all converters will be trip out from DC grid when a fault occur in the grid because breaking time of mechanical DC circuit breaker is longer than trip time of converter. This means protection coordination is unavailable and cause a black out. To solve this problem, high speed DC circuit breaker is necessary. For this reason, KEPCO has been studied DC system protection and circuit breaker. In recent study, KEPCO designed, developed and finally performed site installation and testing at Gochang Power Testing Center. In Gochang Power Testing Center, +/−750Vdc DC system is already installed and in use for various demonstration tests such as performance test of DC device, fault test, operation test and so on. DC source is VSC(Voltage Source Converter) and power utilities(ESS, Diesel Generator, PV, …) are connected.

FAULT ANALYSIS IN DC SYSTEM

To select breaking capacity specification, fault analysis is performed. IEC 61660 presents fault analysis of DC system. However, the analysis is based diode type rectifier. Currently, VSC(Voltage Source Converter) is widely used on power system so fault analysis base VSC is needed. In fault current on DC system based VSC, there are current steps as shown in figure 1.[1]
Figure 3. Testing Site DC System Model

Figure 3 is test site DC line model. Test site modelling and simulation is performed by PSCAD/EMTDC. Several case studies by changing fault location are simulated. Most critical transient case is F1 fault location shown in figure 3. Maximum fault current is about 8kA as shown in figure 4.

SEMICONDUCTOR TYPE DC BREAKER

Semiconductor type circuit breaker consist of two IGBT divers and one Surge Arrester(SA). IGBT drivers and SA are composed of parallel circuits. In normal conditions, current path is circuit of IGBT drivers. In fault conditions, IGBT turn off and current path change to circuit of SA. SA generates voltage as per current value and break the circuit by exhausting energy to heat. These current path steps are shown in figure 5 and 6.

Table 1 shows detail specification of developed semiconductor type DC circuit breaker.

<table>
<thead>
<tr>
<th>Category</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topology</td>
<td>Power Semiconductor</td>
</tr>
<tr>
<td>No. of Circuit</td>
<td>4 Circuit</td>
</tr>
<tr>
<td>Rated Voltage</td>
<td>DC 1,000V</td>
</tr>
<tr>
<td>Rated Current</td>
<td>1,000A (700A)</td>
</tr>
<tr>
<td>Short Time Rated Current</td>
<td>3,000A, 1ms</td>
</tr>
<tr>
<td>Rated Power Frequency withstand Voltage</td>
<td>Pole to Ground : 4kVdc, 1min</td>
</tr>
<tr>
<td>Turn-off delay time</td>
<td>Under 100 μs</td>
</tr>
<tr>
<td>Total Breaking Time</td>
<td>&lt;2ms</td>
</tr>
<tr>
<td>Cooling Capacity</td>
<td>5kW/1 Circuit, Air</td>
</tr>
<tr>
<td>Control Method</td>
<td>Gate Control</td>
</tr>
<tr>
<td>Control Power</td>
<td>24Vdc or 110Vdc</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Over 90%</td>
</tr>
</tbody>
</table>

Semiconductor type has high speed breaking time 2ms. However, it has deficient rated current which is 3kA. It is not enough to cover 8kA which is the most critical case.
current on previous simulation study. Additionally, there is loss on normal condition current path because of IGBT characteristic. Because of this reason this device is difficult to apply on normally closed circuit breaker of power system even if the efficiency is over 90%. To solve these weakness of semiconductor type, this paper propose hybrid type DC circuit breaker.

HYBRID TYPE DC BREAKER

Hybrid type circuit breaker consists of one mechanical fast switch and two IGBT drivers and on SA. These three components are composed of parallel circuits. This type operates in three stages. First is normal condition that current path is circuit of mechanical switch. Second is fault condition that mechanical switch opened and current path change to circuit of IGBT drivers. In third stage, IGBT turn off and path change to SA. SA cut off the circuit finally. These current path steps are shown in figure 7, 8 and 9.

Table 2 shows detail specification of developed h type DC circuit breaker.

<table>
<thead>
<tr>
<th>Category</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topology</td>
<td>Hybrid Type : Fast SW + IGBT</td>
</tr>
<tr>
<td>No. of Circuit</td>
<td>1 Circuit</td>
</tr>
<tr>
<td>Rated Voltage</td>
<td>DC 1,000V</td>
</tr>
<tr>
<td>Rated Current</td>
<td>1,000A / 700A</td>
</tr>
<tr>
<td>Short Time Rated Current</td>
<td>12.5 kA, 1s</td>
</tr>
<tr>
<td>Rated Power</td>
<td>Pole to Ground: 4kVac, 1min</td>
</tr>
<tr>
<td>Frequency withstand Voltage</td>
<td></td>
</tr>
<tr>
<td>Closing Time</td>
<td>&lt;30ms</td>
</tr>
<tr>
<td>Opening Time</td>
<td>&lt;2ms</td>
</tr>
<tr>
<td>Total Breaking Time</td>
<td>&lt;4ms</td>
</tr>
<tr>
<td>Control Method</td>
<td>Manual or Electrical Control, Gate control</td>
</tr>
<tr>
<td>Control Power</td>
<td>24Vdc or 110Vdc</td>
</tr>
<tr>
<td>Surge Arrestor</td>
<td>750V</td>
</tr>
<tr>
<td>Capacitor</td>
<td>750V</td>
</tr>
</tbody>
</table>

Hybrid type DC circuit breaker has 4ms breaking time as shown in table 2. This time performance is slow than semiconductor type. However, there is no loss on hybrid type because IGBT is turn off in normal condition. Rated current is 12.5kA which can cover 8kA.
DC RELAY

DC relay for developed circuit breaker detect fault by monitoring rate of current change (di/dt) and output trip signal under 1ms. FPGA (Field Programmable Gate Array) is used to reduce time of detect and output signal. Table 3 shows the detail specification of DC relay.

Table 3. Specification of DC Relay

<table>
<thead>
<tr>
<th>Category</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protection</td>
<td>- Over Current Protection(76D)</td>
</tr>
<tr>
<td></td>
<td>- Fault Selected Protection</td>
</tr>
<tr>
<td></td>
<td>- Over Voltage Protection(45F)</td>
</tr>
<tr>
<td></td>
<td>- Under Voltage Protection(80F)</td>
</tr>
<tr>
<td></td>
<td>- Reverse Current Protection(32D1, 32D2, 32D3)</td>
</tr>
<tr>
<td></td>
<td>- Interlinked Breaking(85)</td>
</tr>
<tr>
<td>Control</td>
<td>Section Control, Local/Remote,</td>
</tr>
<tr>
<td></td>
<td>Direct Open/Close, Automatic Test, Program Logic</td>
</tr>
<tr>
<td></td>
<td>Control, Line Test, Auto Reclose, ...</td>
</tr>
<tr>
<td>Metering</td>
<td>- Current, Voltage, Power, Watt</td>
</tr>
<tr>
<td>Output Contacts</td>
<td>- 30 Channel</td>
</tr>
<tr>
<td>Control Inputs</td>
<td>- 60 Channel</td>
</tr>
<tr>
<td>Communications Ports</td>
<td>- Port : RJ45, RS232, RS485, Ethernet 10/100BaseT</td>
</tr>
<tr>
<td></td>
<td>- USB : PC Application Interface Software</td>
</tr>
<tr>
<td></td>
<td>- Protocol: DNP 3.0, MODBUS, IEC 60870-5-101/104,</td>
</tr>
<tr>
<td></td>
<td>IEC 61850</td>
</tr>
</tbody>
</table>

SITE INSTALLATION

Developed two type of DC circuit breaker are manufactured and installed in Gochang Power Testing Center. The circuit breakers are connected with DC bipolar +/-750V line. Figure 11 and 12 shows installed products which is semiconductor type and hybrid type, respectively. Both are underground line circuit breaker.

Figures 12. Site Installation of Hybrid Type

TEST RESULT

To test performance of developed two circuit breaker, DC AFG (Artificial Fault Generator). This DC AFG is manufactured to make fault condition in DC +/-750V bipolar line. Fault type (line to ground fault or line to line fault) and fault resistance (0 to 8 ohm) can be selected by user. To consider the most critical case, line to line fault tests are performed. Figure 13 shows one of the site test by the DC AFG.

Figure 13. Site Fault Test using DC AFG

Result of fault test of semiconductor type DC circuit breaker is shown in figure 14. Positive line to neutral line fault with 0.5 ohm fault resistance is generated by DC AFG. As shown in figure 14 and 15, total breaking time is under than 2ms. Measured time is about 1.5ms.

Figure 14. Fault(2Ω) Test of Semiconductor Type
Result of fault test of hybrid type DC circuit breaker is shown in figure 15. Same fault condition is generated by DC AFG. As shown in figure 16 and 17, total breaking time is about 4ms.

CONCLUSION

Fault study, design, development, site installation and performance test for high speed DC circuit breakers are presented in this paper. KEPCO developed two type of DC circuit breaker. Semiconductor type has high speed breaking time under 2ms. However, it has weakness for capacity and losses. To solve the weakness of semiconductor type, hybrid type DC circuit breaker is proposed. There is no losses and large capacity in this type. However, breaking time is about 4ms which is not better than first one.

Fault current time in DC system is faster than AC system. It is dependent on topology of source and time constant of power system. The time is scale is millisecond or under millisecond. As per study for DC replay, minimum communication delay time for detection and sending command output is 1ms. For this delay time, it is difficult to develop DC circuit breaker which can block all fault type in DC system.

It is necessary to develop high speed circuit breaker for DC system. To apply in power system, however, there are a lot of requirements such as losses, capacity, size, prices. Above all, it is difficult to secure fast breaking time of circuit breaker compared with maximum fault travel time. Therefore, power system design considering fault time is important with developing breaking time of DC circuit breaker.

REFERENCES


[4] HongJoo Kim, ”Demonstration of the LVDC distribution system in an island”, CIRED 2017