DESIGN AND VERIFICATION OF DC 1000V AIR CIRCUIT BREAKER FOR BROAD RANGE OF PROTECTION IN LVDC DISTRIBUTION

Young Kook Kim
LSIS Co., Ltd. – Republic of Korea
ykkimd@lsis.com

Sangchul Lee
LSIS Co., Ltd. – Republic of Korea
sangclee@lsis.com

Woojin Park
LSIS Co., Ltd. – Republic of Korea
wjpark@lsis.com

Kilyoung Ahn
LSIS Co., Ltd. – Republic of Korea
kyahn@lsis.com

Youngguen Kim
LSIS Co., Ltd. – Republic of Korea
youngk@lsis.com

ABSTRACT
This paper presents a protection device covering broad range of currents in LVDC distribution. As direct current has significantly different electrical characteristics compared to alternate current, it is important to implement protection strategies. To fulfill this requirement, this paper firstly introduces design architecture of sensing unit, shunt embedded and override sensor connected to digital trip system. Based on current measurement system, we focus on designing arc splitting component called "Arc Chute". To verify this component, various tests according to IEC 60947-2 were applied to DC ACB (Air Circuit Breaker).

INTRODUCTION
In 21st Century, the trend of global market in low voltage distribution has been focused on DC system as conventional AC generation had occurred side effect such as environment pollution. Among various alternative means to solve the problem, PV and ESS system have been a practical solution on account of its convenience to generate infinitely and store the energy at any time [1].

In order to use these systems properly, it is crucial to apply the proper protection devices into DC distribution line to guarantee the protection. As shown in Fig. 1, there is an example of ESS system. As fault current was occurred in battery rack, the protection system is to be implemented in power conditioning system otherwise the entire grid has possibility to shut down and converter device is no longer available [2].

To correspond market trend, in 2017, LSIS distributed an air circuit breaker for DC 1000V as shown in Fig 2. This system covers 65kA/1sec for short time withstand current capacity ($I_{cu}$), and its short circuit current ($I_{cu}$) up to 40kA at 1000Vdc. Moreover, it has 7000 operational cycles at 1000Vdc/2500A circuit [3].

To guarantee this performance, it is clear that there are major challenges in component design. Firstly, as direct current (DC) has no oscillation in electric circuit, there must be different approach to measure the current. Secondly, it is difficult to break direct current during rated and short circuit situation since there is no zero current crossing once the current reaches steady state.

Therefore, DC ACB considers novel design aspects in 2 major parts, sensing, and arc splitting part (blue hatched box) as shown in Fig 3. This paper mainly deals with major design modification applied to our DC ACB. In terms of sensing part, we firstly introduce combination of compact DC shunt and CT type sensors for broad range current measurement. Based on sensing component, the design of arc splitting component in DC environment is then dealt with between short and rated circuit environment.

SENSING ARCHITECTURE IN DC CURRENT
As shown in Fig. 4, it is comparison between DC current and AC current. In this figure, we figure out 2 major differences.

Firstly, compared to AC, DC current has two phases, transient and steady state. In transient state, current rate is distinctive and its differential value is varied depending on time constant ($\tau$).
Fig 4. Comparison between AC and DC behavior

Secondly, it is revealed that there is no fluctuation of the current when it reaches the steady state and there is no drastic change in current flow. Based on two phenomena, we are able to design the DC sensors

**Compact Type Shunt Sensor in Rated Current**

As rated DC current, it is easy to measure the value by applying Ohm’s law \( V=IR \). Therefore, it is needed to design compact type shunt sensor having identical size as shown in Fig. 5. In order to fulfil this there are following principles below:

1. Material has high thermal conductance for keeping low temperature value.
2. Select appropriate material which provides proportional value as current increases.
3. Robust method to bond between terminal and resistance alloy.

To match above conditions, we firstly chose the material, Manganin [4]. This alloy consists of 86% of Copper and other materials. This resistance alloy has high electrical conductivity which temperature during current flowing is comparatively lower than other alloys. Also, this alloy guarantees long-term stability of electrical resistance during high temperature environment.

Secondly, the number and volume of shunt is determined for the compact sensor size with acceptable trip unit range (8μΩ at 1600A). To reach this target value, the following equation is below:

\[
R = \rho \frac{L}{A} = \frac{1}{G A}
\]

Where,
\( \rho \) : (Specific Resistance, [Ω·m])
\( A \) : (Cross Section, [m²])
\( L \) : (Length, [m])
\( G \) : (Electric Conductivity, [S/m])

Thirdly, brazing process is applied once the parameter and feature of the shunt alloy are determined. In this process, restoration atmosphere furnace is used for the copper to copper brazing. During this process, the bonding material (BAg8 brazing filler) has a role to unite between copper terminal and the shunt alloy in high temperature environment in chamber [5].

**DC Sensor for Short Circuit Protection**

In addition to rated current measuring, a circuit breaker is needed to have the protection capability in short circuit current (8~10 \( I_n \)) during early stage of transient phase without external power input to start the trip unit. To fulfil this condition, the component system consists of two parts, Power Current Transformer (PCT) supplying the sufficient energy to operate digital trip relay and Signal Current Transformer (SCT) providing proportional signal to short circuit current measured.

Fig 5. DC Sensor Configuration for Rated Current

Fig 6. DC Short Circuit Current Sensor in DC ACB
To achieve above requirements, LSIS designed a protection module applied to DC ACB as shown in Fig. 6. With this module, DC ACB is able to break 10 \( I_n \) (40kA) short circuit current at 1000Vdc.

**DESIGN OF ARC CHUTE FOR DC CURRENT**

Once the sensor component is well designed and equipped in DC ACB, it is crucial to design the arc breaking component in normal air condition. Based on the design parameter comparison, we achieve broad range of current breaking in DC ACB system.

**Importance of Arc Energy Dissipation**

As shown in Fig. 7, there is an equivalent LR circuit model with the governing equation below:

\[
U_e = V_a + L \frac{di}{dt} + Ri
\]  

(1)

where,

\( U_e \) : Source Voltage  
\( V_a \) : Arc Voltage  
\( L \) : Inductance  
\( R \) : Resistance

According to Ohm’s law, DC current, \( i \) is forced to “0” at breaking if \( V_a \) has greater value than source voltage, \( U_e \) [6]. As shown in Fig. 8, the general behaviour of close-open sequence of rated (1000Vdc/2500A) and short circuit (1000Vdc/40kA) current test was illustrated. From the figure, it is found that that the arc voltage, \( V_{arc} \) is nonlinearily increased during current drop to zero in the time zone, \( T_{arc} \). We called it arc quenching effect.

Therefore, in terms of arc quenching, it is reasonable to find out the distinctive parameters in the arc chute maximizing the arc quenching effect (\( V_{arc} \uparrow \), \( I \downarrow \)) at DC Breaking.

**Parameter Design Comparison in DC Arc Chute**

As mentioned, the arc quenching in DC current breaking depends mainly on increasing arc potential. In this reason, there are modifications in three aspects in arc chute, number of arc grid, length of arc plate, and existence of arc guide for amplifying the effect. Table 1 shows the relative comparisons of three parameters

<table>
<thead>
<tr>
<th>Type</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Plate, N</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>Length of Arc Plate, L</td>
<td>1</td>
<td>1.1</td>
</tr>
<tr>
<td>Existence of Arc Guide</td>
<td>none</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 1. Design Parameter Specification Comparison

The reason to select the above parameters is following:

1. Numbers of arc plate, \( N \) : we anticipate the better breaking capacity in Type B as arc plasma are split more during the breaking phase.
2. Length of Arc Plate, \( L \) : As DC current generates lower pressure during breaking phase compared to AC current, we expect that the longer arc grid contacts the arc plasma faster.
3. Existence of Arc Guide : In rated current, the pressure in the arc chute is relatively low enough so that the arc plasma connects to the each of arc plate. Arc guide which is made of thermosetting resin hiding the lower edge of arc grid so that the arc plasma at least connects higher arc plate position.

Based on sample design comparison, DC current breaking tests were performed based on IEC standard in LSIS Power Testing & Technology Institute (PT&T) [7]. The test platforms have identical condition equipping DC current sensors. For the result comparison, there are two parameters measured, \( V_{arc} \) and \( T_{arc} \), respectively.
CONCLUSIONS

This paper paid attention to importance of sensing and arc quenching component in various DC current environment. As DC current has different electrical behaviour compared to AC current, the sensing system design was focused on uniting the two different types, a shunt type for related current and CT current sensor for the short circuit current, respectively.

Based on this system component equipped in DC ACB, the breaking tests were performed to verify the significance of parameter selection in arc chute component. From the result, we found that arc plate, the number of arc plate, and arc guide have a role to increase $V_{\text{arc}}$ effectively.

REFERENCES


