ARC PHENOMENA AND METHOD OF ARC EXTINCTION IN AIR CIRCUIT BREAKER

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ABSTRACT

Air Circuit Breaker (ACB) is an electric control device that interrupts the abnormal currents which result from the over-loads or short-circuits in Low voltage(less than 1,000Vac or 1,500Vdc) distribution line. Recently, higher current breaking performance has become crucial in providing the reliability for the modern devices requiring small scale and high performance. When ACB opens, in order to isolate a fault no matter whether it is arcing fault or short circuit fault, an arc exist between the contacts. Immediately after the interruption, arc reignition can occur, thus causing failure of interruption. Therefore discontinuity of power supply is prolonged in this way. Therefore correct knowledge of microscopic processes that can initiate and extinguish an arc is of great importance for reliability and quality of power in power systems. An understanding of the interruption and re-ignition of an arc discharge has obvious significance for the design and development of a wide variety of industrial devices.[1]. When a short circuit occurs, a fault current flows between the contacts of ACB even though they are separated by the protective control system until ACB breaks the fault current. In terms of arc extinguishing, ACB should generate as high an arc voltage as possible during breaking phase. The arc resistance (high arc voltage) could lead the main circuit to zero arc current so that arc plasma is eliminated.

Based on this, arc chamber(arc extinction system) of ACB should be designed for increasing arc resistance during breaking period of the current. There are conventional several methods that are widely known as arc extinction methods and most of them involve method for increasing arc voltage.

In this paper, experiments and CAE analysis were carried out to refine the criteria of the arc extinction and verify the validity of the arc extinguishing method

INTRODUCTION

ACB is a typical type of circuit breaker that interrupts the fault current in the event of an electrical accident as well as switches the electrical circuit in the air condition. External view and basic components of ACB are shown as follows.

[Withdrawable type] [Fixed type]

Fig.1 External view of ACB[2]

Recently, there have been a lot of studies on the arc extinction method for breaking high level of current(fault current such as short circuit) in the air. Particularly well-known methods are those related to elongation of the arc length and cooling the arc and this is because the arc voltage can be increased through these methods. To understand a procedure of arc generation, the internal structure of ACB should be considered. The internal view(current path at breaking period) of ACB is shown in Fig. 2

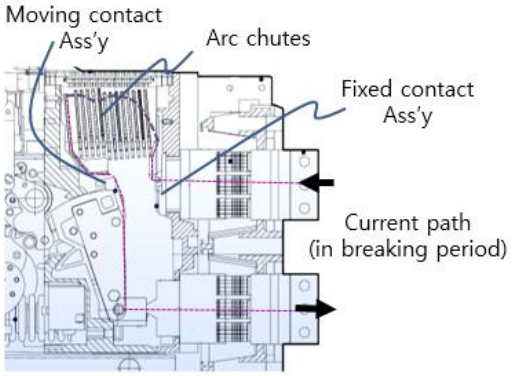

Fig.2 Internal view of ACB[2]

When the two main contacts(movable & fixed) are separated in the event of a fault state such as a short circuit, an arc plasma phenomenon occurs between the contacts of ACB. At this time, the performance of the circuit breaker depends on how the arc phenomenon is controlled by its arc quenching method. It is well known that arc quenching performance is determined by various factors such as the moving speed of the movable conductor, the arrangement

of the arc chute, material type of the components and etc. The performance of the circuit breaker is not determined by any one method, but the desired performance can only be achieved if all of the factors mentioned above are harmoniously combined.

Therefore, it is necessary to first investigate what is in the basic arc extinction method in air medium and understand the process from generation to extinction of arc.

BASIC PRINCIPLE OF ARC EXTINCTION

The procedure of the arc extinction is same as procedure of recovering the insulation of the circuit. In terms of arc extinguishing, ACB should generate high arc voltage during breaking phase. As shown in Fig. 3, 1st order time invariant linear equation was derived from equivalent circuit model. From the equation, it is proven that arc resistance to infinite value leads to zero arc current so that arc plasma is eliminated.

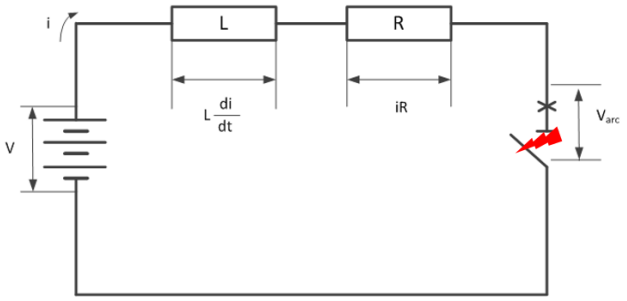

Fig.3 R-L Circuit

From above equivalent circuit, we derive

$$V = L\frac{di}{dt} + iR + V_{arc} \qquad (1)$$

Equation (1) is rewritten below

$$L\frac{di}{dt} = V - iR - V_{arc} \qquad (2)$$

At breaking phase,

If $V_{arc} > V$ then, $\frac{di}{dt} < 0$ (3)

Equation (3) explains the current limitation phenomena in the breaking period and shows starting point of the current limitation. Therefore, equation(2) is written as follows.

$$V_{arc} = (i_{arc} \cdot R_{arc}) = V \qquad (4)$$

$$\therefore\ i_{arc} = V/R_{arc} \qquad (5)$$

If $R_{arc} \rightarrow \infty$, then $i_{arc} \rightarrow 0$

From the above equation, we can find out that the current flowing between the contacts depends upon the arc resistance during the arcing period. The larger the amplitude of the current, the higher becomes the arc temperature and the density of electric charge carriers generated in the arc. This makes it much more difficult for the contact gap to become insulating after current interruption at current zero. In addition to the current amplitude, the current steepness (di/dt) near current zero is of crucial importance for the current interruption process. A higher di/dt means that the switching gap has less time to change from conducting to insulating state, before the gap is exposed to the transient recovery voltage.[3] On the other hand, the greater the arc resistance(di/dt<0), the smaller the current that flows between the contacts. It is therefore necessary to understand how the behaviour of the arc progresses during the current breaking period and what methods are being used to increase the arc resistance.

PROCEDURE OF THE ARC EXTINCTION

The process of generation and extinction of the arc is shown in Fig.4. The first step of arc generation is an arc initiation between two main contacts of ACB by starting separation of movable conductor. The magnitude of arc voltage at this time is very small so that hardly recognized sometimes. In the 2'nd step, As the distance between two contacts increases, the arc voltage increases gradually. When arc voltage distribution starts by the arc chutes, the arc voltage reaches its maximum value in the last step. The breaking time is determined by how quickly the arc voltage is raised, and the shorter the breaking time, the less the damage to the main circuit. The behaviour of the arc may be also influenced by the arrangement and the shape of the arc chutes.[4][6] Fig. 5 shows arc voltage changes due to the behaviour of arc.

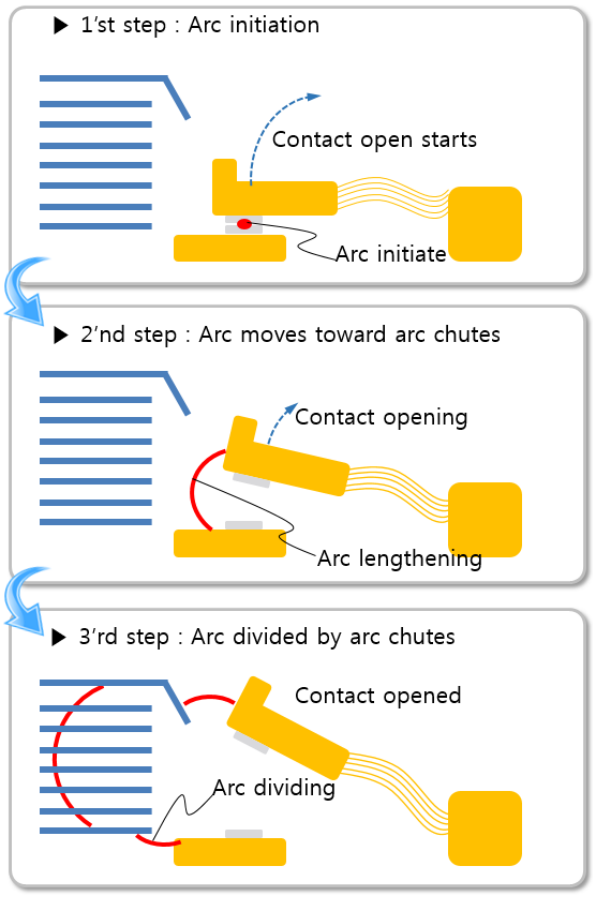

Fig. 4 Arc extinguishing procedure in ACB system

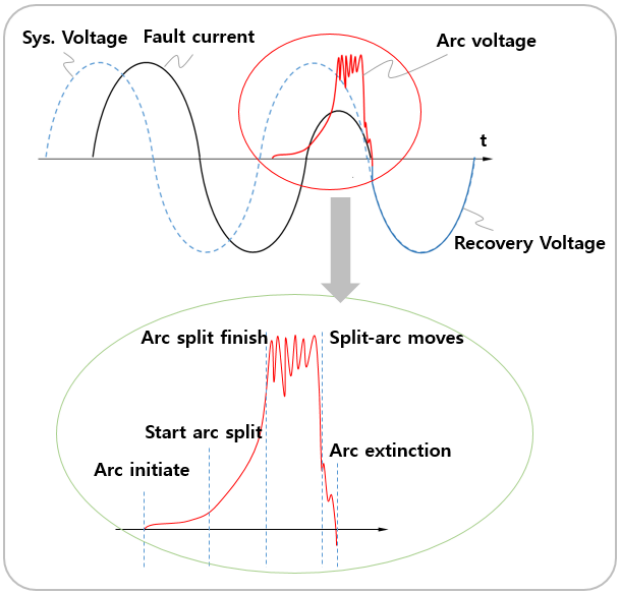

Fig. 5 Arc voltage change due to arc behaviour

The most important thing in the procedure of the arc extinction is how fast the arc voltage reaches its maximum value and the high arc voltage can be maintained. This is the most important criteria that determines the performance of the breaker. Fig. 6 shows experimental results of the procedure of arc extinction phenomena of ACB using high speed camera.

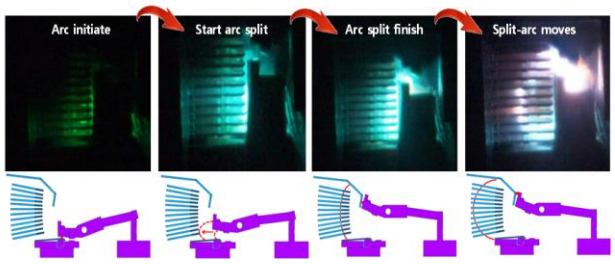

Fig. 6 Results of arc extinction procedure

METHOD OF ARC EXTINCTION

The arc extinction method can be broadly divided into two methods, one is to increase the arc length while reducing the cross sectional area of the arc column, and the other is to cool the arc by using the arc chute and the gassing material.

The resistance of the arc can be increased by lengthening the arc. The air gap between contacts(Fixed & Moving) acts as conductor due to the connection of arc plasma so that by increasing the gap between the contacts then the resistance of the arc can be increased. The resistance of the arc is directly proportional to its length. The length of the arc can be increased by increasing the gap between contacts. In addition, Reducing the cross section area of the arc directly implies up on the voltage to be maintained for the arc persisting. If the area has been reduced, the resistance of the arc path increases so that the voltage of the arc should be high enough to maintain the arc.

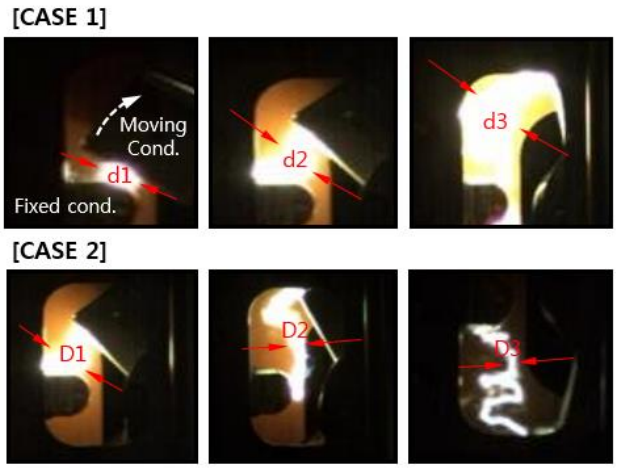

Fig. 7 The difference in the cross-sectional diameter of the arc column

Fig. 7 shows the difference in the cross sectional diameter of the arc column during the current interruption period by the experimental test. The difference in the cross-sectional diameter(d > D) of the arc column occurs depending on the structure of the arc chamber. This difference is related to the arc voltage. This difference shows that the level of arc voltage is higher in CASE2 than CASE1, and the performance of arc extinction in CASE2 is also better than CASE1. Therefore, it can be seen that the smaller the diameter of the arc column is, the higher the arc voltage is, and thus the current breaking capacity is improved.

Natural combination of ionized particles takes place more rapidly if they are allowed to cool. Therefore, Cooling helps in the deionization of the medium between the contacts. This increases the arc resistance. Efficient cooling may be obtained by various way of cooling systems such as arc chutes, gassing material, a air or gas blast directed along the arc and etc. Specially, the cooling effects of spallation particles which are ejected from the gassing material such as PA6 and PA66 surface to the thermal plasma, where they are ablated. That ablation can involve cooling of thermal plasma because of its latent heat for thermal decomposition and mixing of ablated vapour.[5] For this reason, lots of researches on new materials that help extinguishing arc are being carried on continuously. The resistance of the arc also can be increased by splitting the arc into a number of smaller arcs in series. Each one of these arcs experiences the effect of lengthening and cooling. The arc may be split by introducing some conducting plates between the contacts.

ANALYSIS STUDY

The magnetic field driving force of the arc column varies depending on the shape and arrangement method of the arc chute. To confirm this fact, the main circuit part of the

circuit breaker was finite element modeled with the arc column shown in Fig. 8.

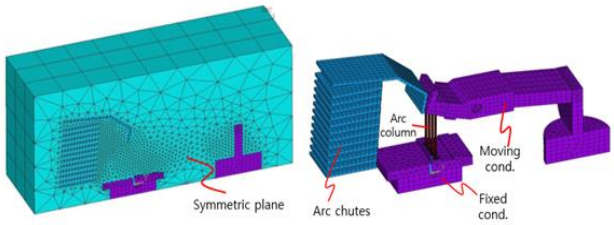

Fig. 8 F.E.Model of ACB

The symmetric half model is used for electromagnetic analysis to find out electromagnetic forces acting on the arc column according to the shape of arc chutes. The results of electromagnetic force in main circuit of ACB is shown in Fig. 9.

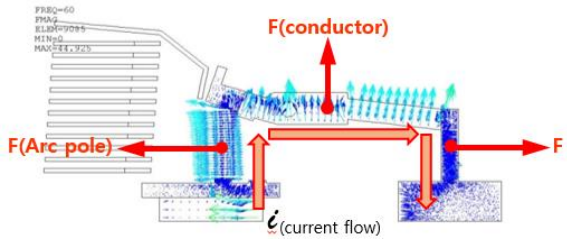

Fig. 9 Results of electromagnetic force in main circuit

From the result of the vector plot of the electromagnetic force in the main circuit, it is found out that the direction of the force of the arc column is directed to the arc chutes.

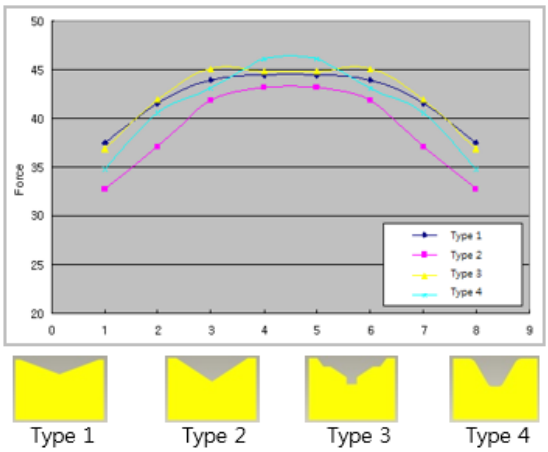

Fig. 10 Results of Electromagnetic forces in arc column for Arc drawing to Splitting Zone

Fig. 10 shows the change of the electromagnetic field driving force of the arc column depending on the shape of the arc chutes from Type 1 to Type 4.

According to the results of electromagnetic analysis of the current break system, there are differences of electromagnetic nodal forces acting in arc column between the shapes of arc chute. It can be seen that the greater the magnetic field driving force of the arc column, the better the breaking performance of ACB.

CONCLUSIONS

In order to understand the arc behaviour(the procedure of arc extinction) caused by the effect of various kinds of arc extinction methods, both electromagnetic analysis and experimental study are carried out.

During opening of current carrying contacts in air circuit breaker the medium in between opening contacts become highly ionized through which the interrupting current gets low resistive path and continues to flow through this path even the contacts are physically separated.

Increasing the resistance of the arc through various methods(Elongation & Cooling of the arc) of arc extinction helps interrupting current flow more efficiently.

According to the electromagnetic analysis of the current break system, there are differences of electromagnetic nodal forces acting in arc pole between the shapes of arc chute.

It has been proved that the methods of arc extinction suggested in this paper are helpful for interrupting current flow by CAE analysis and the experimental test using high speed camera as well.

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