Development of 460V/ 225A/ 50kA Contact System in Current Limiting Molded Case Circuit Breakers

Young-Kil Choi* and Chan-Kyo Park*

Abstract - Low voltage circuit breakers are widely used in power distribution systems to interrupt fault current rapidly and to assure the reliability of the power supply. This paper is focused on understanding the interrupting capability, more specifically of the contacts and the arc runner, based on the shape of the contact system in the current molded case circuit breaker (hereafter MCCB). Moreover, in order to improve the interrupting capability of the circuit breaker, the estimation and analysis of the interrupting capability, based on the 3-D magnetic flux analysis, were developed. Furthermore, this paper also presents results of the estimation and analysis of the interrupting capability when applied to different model breakers. In addition, this paper analyzes the efficiency of the interrupting tests by forming false current paths consisting of a three-division cascade arc runner in the contact system. With regards to the interrupting test, there is a need to assure that the optimum design required to analyze the electromagnetic forces of the contact system generated by the current and flux density be present. Based on the results of this study, this paper presents both computational analysis and test results for the newly developed MCCB 460V/ 225A/ 50kA contact system.

Keywords: MCCB, Molded Case Circuit Breaker, Contact System, Arc Interruption

1. Introduction

The electrotechnology used for power apparatuses as well as the computerization of the systems related to buildings, factories, and houses has rapidly increased as a result of informationalization, industrialization and modernization of cities, as well as the diversification of the living environment. As numerous pieces of electronic equipment and electronic controls are now being employed in the load of these electronic apparatuses, many of the potential threats to power quality, such as the occurrence of harmonics, rise of surge voltage, and increases in interrupting capability, have occurred. In addition, widespread dependence on electric energy, with the OA/ FA/ equipment industry at the forefront, has increased significantly. Therefore, in order to assure a reliable electric power supply, the importance of preventing electric power interruptions, and even more so, power failures, has amplified drastically. This increase in market demand has provided the impetus for the MCCB industry to bring about improvements in interrupting capability and reliability and to develop appropriate protection systems. However, in order to effectively design/manufacture cabinet panels there is a need to achieve the standardization of smaller sized cabinet panels and to increase their interrupting capability, as well as to develop alternative technologies to miniaturize circuit breakers so as to decrease the space required for installation.

To meet market demands and develop the 460V/ 225A/ 50 kA contact system, this study strived to develop an estimation and analysis method, based on the design of the shape of the contact system in the MCCB, to calculate the interrupting capability. This study also measured the efficiency of interrupting capability by utilizing the shape of the arc runner in the contact system as the false current path. Based on the results of the research, this paper proposes a newly developed MCCB, and through the current interrupting test, proves the efficiency of this newly designed product. By introducing related study results, this paper has contributed to the improvement and verification of the interrupting capability in designing the shape of the contact system in the MCCB. This paper also promotes the miniaturization as well as the performance improvement of related products.

2. Estimation and Analysis of the MCCB [1]

As the arc generated between the two contacts in the MCCB's contact system remains in a plasma state, this arc can be easily quenched if a strong magnetic flux is distributed surrounding it. In order to form this strong magnetic flux, related industries have strived to improve the interrupting capability of the MCCB by using a magnet

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grid. As per the experiment [2] however, while the interrupting capability is increased, the arc driving magnetic flux formed by the grid, as a result of the magnetic saturation phenomenon, is unable to increase beyond a certain range. To solve this problem, various efforts have been made to form a strong arc driving magnetic flux. Some researchers have suggested that improving the shape of the contact could result in the formation of a strong arc driving magnetic flux [3]. As the arc driving magnetic flux formation increases in accordance with the amount of interrupting current, it is advantageous to use a high level of interrupting capability even in cases where the interrupting capacity is increased. Therefore, this paper has strived to determine the proper size for the arc driving magnetic flux based on various contact shapes using a 3-D magnetic flux analysis, a step that should be taken prior to the designing of a new contact system for the MCCB. Based on these results, this paper presents the research carried out to develop an estimation and analysis method for the interrupting capability.

The purpose of the method is to obtain a total magnetic flux that can drive the arc between two contacts.

First, four MCCBs with known capability were selected in order to carry out a comparison of the various contact systems with the object of proving the method.

Next, according to each MCCB, analytic lines for the 3-D magnetic flux were selected as shown in Fig. 1: (1) is the basic line that passes the center of the arc column, (2) is the line that passes ΔX from the center of the arc column, (3) is the line that passes twice the distance of ΔX from the center of the arc column.

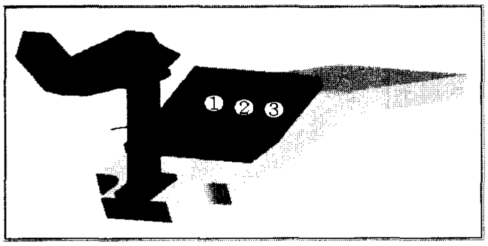


Fig. 1 Analytic lines for the magnetic flux to estimate the interrupting capability

Second, the magnetic flux density of these three lines was calculated using a 3-D magnetic flux approach. Based on these results, the size of the arc driving magnetic flux generated by the various contact systems was analyzed, providing an understanding of the problems associated with improving the design of the contact system for the MCCB. Each analytic line is maintained at a certain height from the bottom of the stationary contact, and the arc column is set up as a round column as can be seen in the paragraph under 2.1.

Next, based on the above contents a 3-D magnetic flux analysis is carried out to compare the interrupting capabilities of the existing products by founding the following analytic conditions.

2.1 Conditions for the 3-D magnetic flux analysis

In some papers [4], the effects of the magnetic flux distribution on the contact system of the MCCB are analyzed along with the variation of the arc current.

In this paper, the following conditions are considered briefly.

- Arc radius: 2 mm
- Interrupting current: 25kA
- Distance between the two contacts: 8 mm
- Area of the magnetic flux analysis: arc column

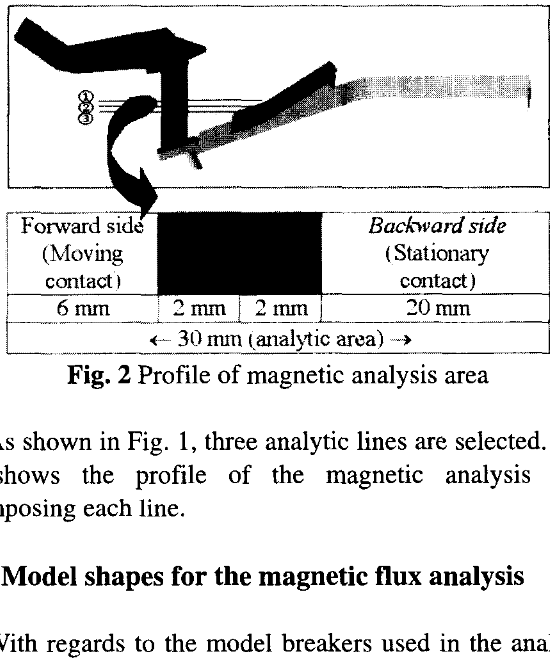


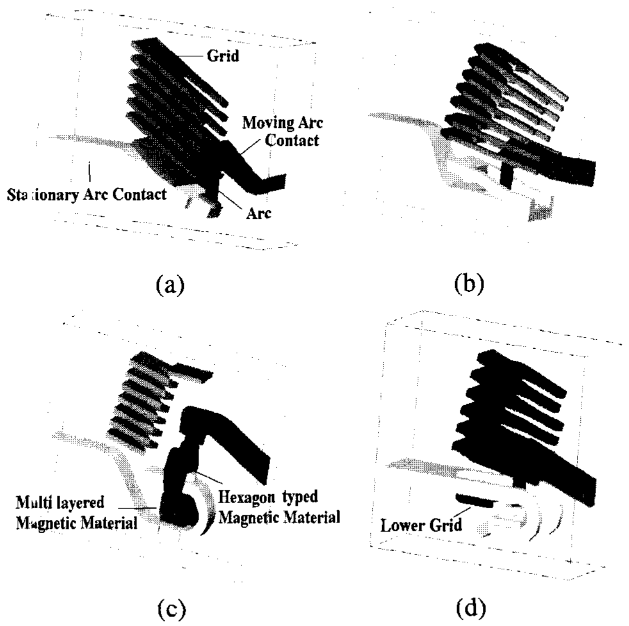
Fig. 2 Profile of magnetic analysis area

As shown in Fig. 1, three analytic lines are selected. Fig. 2 shows the profile of the magnetic analysis area composing each line.

2.2 Model shapes for the magnetic flux analysis

With regards to the model breakers used in the analysis of the magnetic flux, the MCCB manufactured by the company participating in this research, the MCCB made by the L-company, the MCCB manufactured by the S-M company in Europe, and the MCCB made by the M-company in Japan were selected. All of these products are presently available on the market. The selected model breakers' options were unified at a rate of current of 225A of 225 AF. However, each model had its own rated current interrupting differently.

Fig. 3 exhibits the various contact systems used. Fig. 3(a) is the MCCB for the sponsor company's contact system, which is made without an isolation cover between the two contacts. Fig. 3 (b) is the MCCB manufactured by the L-company in Korea, in which an isolation cover is installed to prevent short-circuit current from occurring between the stationary arc contact and the moving arc contact. Fig. 3 (c) is the MCCB manufactured by the S-M company in Europe, in which the stationary arc contact is shaped like a J and a hexagon magnetic material can be found both to the left and right of the contact system. In addition, a multi-layered magnetic material is placed under the stationary arc contact. Fig. 3 (d) is the MCCB manufactured by the M-company in Japan, in which the shape of the stationary arc contact is bent into a half-coil shape and a sub-grid is placed within the stationary arc contact.



(a) MCCB manufactured by the sponsoring company
(b) MCCB from L-company
(c) MCCB from the S-M company in Europe
(d) MCCB from the M-company in Japan

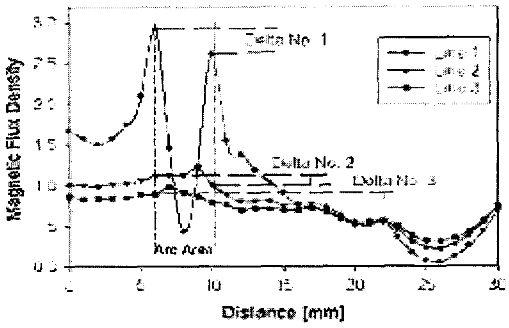
Fig. 3 Model shapes of the contact systems for the magnetic flux analysis

2.3 Magnetic analysis to evaluate the interrupting capability

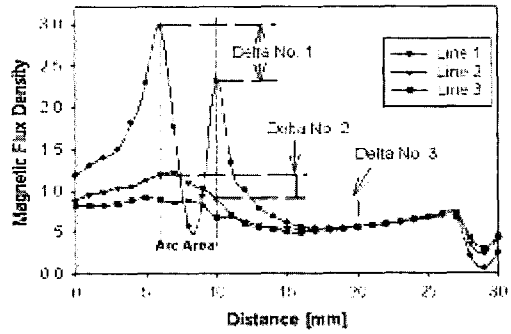
By applying the conditions set in 2.1, a 3-D magnetic analysis is executed to evaluate the interrupting capability of the contact systems of the selected models. Fig. 4 exhibits the results of the analysis conducted on the three analytic lines, which were in turn obtained as a result of a 3-D magnetic analysis performed on the four models.

The arc area in Fig. 4 represents the arc column space in Fig. 2. Using the arc column as the center, the moving contact part is located at the left side, and the terminal of the stationary arc contact on the right.

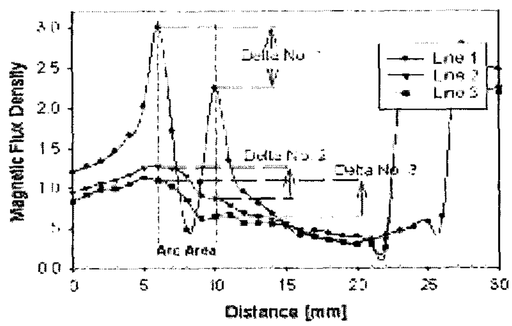
The magnetic flux density seen on the left of the arc column forms the forward arc driving magnetic so that the fault current is interrupted by forcing the arc column to the back and extending the arc.



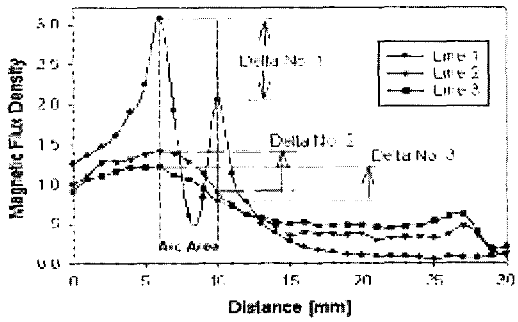
(a) MCCB of the sponsor company



(b) MCCB manufactured by the L-company (domestic)



(c) MCCB manufactured by the S-M company in Europe



(d) MCCB made by the M company in Japan

Fig. 4 Results of the 3-D magnetic flux analysis on the analytic lines

Conversely, the magnetic flux density seen on the right side of the arc column forms the reward arc driving magnetic flux at the contact system by leading the arc to the front from the back. As the total magnetic flux (the forward minus the rearward) is bigger positively, there is a higher possibility that the arc be quenched and that the fault current occurring between the two contacts be interrupted.

In other words, if the gap between the forward and rearward arc driving magnetic flux increases, the interrupting capability can be understood as to be also increasing.

Delta No. 1 of Fig. 4 exhibits the results of the 3-D magnetic flux analysis performed on analytic Line 1, which passes through the arc column, and shows the gap between the forward and rearward arc driving magnetic flux outside of the arc column. Delta No. 2 displays the results of the 3-D magnetic flux analysis conducted on analytic Line 2. Delta No. 3 indicates the results of the 3-D magnetic flux analysis undertaken on analytic Line 3. A comparison of the size of Delta No. 1 of the four models, revealed the following: the MCCB manufactured by the M-company in Japan was the biggest, followed by the MCCB made by the S-M company in Europe, the MCCB made by the L-company in Korea, with the MCCB of the sponsor company being the smallest.

In addition, with regards to the size of the magnetic flux density, the M-company in Japan and the S-M company from Europe recorded levels of under 0.5T within 15mm of the analytic lines, thus exhibiting a low value for rearward arc driving magnetic flux compared to the others. Such a low value for the arc driving magnetic flux can contribute more significantly to interruptions in the fault current, thus heightening the arc resistance while also raising the arc voltage occurring between the stationary arc contact and the moving arc contact. The comparison of the sizes of Delta No. 2 and Delta No. 3 found in Fig. 4, using a 3-D magnetic flux analysis, exhibited similar results as those for Delta No. 1. Of special note, the MCCB manufactured by the M-company in Japan demonstrated the most prevalent difference in Delta values. Moreover, as a result of the low magnetic flux density at the terminal of the stationary arc contact, this MCCB minimizes the influence of the reward arc driving magnetic flux.

Summarizing the above-mentioned contents into Table 1, the conclusion was reached that the shape of the sponsor company's MCCB contact system should be improved

Table 1 Results of the 3-D magnetic flux analysis

Company	Results of the 3-D magnetic analysis			Rated interrupting capability
	ΔNo.1	ΔNo.2	ΔNo.3	
Sponsor company	0.30	0.13	0.12	25kA
L-company	0.70	0.30	0.20	35kA
S-M company	0.77	0.42	0.48	65kA
M-company	1.00	0.50	0.45	50kA

* The MCCB manufactured by the S-M company in Europe is made up of two contacts/phase systems

2.4 Development of stationary arc contact with strong magnetic flux for the arc driving magnetic force

According to the results of the 3-D magnetic flux analysis, the formation of higher density of forward arc driving magnetic in the arc, which occurs between the two contacts, increases the length of the arc and improves its interrupting capability by increasing the arc resistance.

To increase the density of the forward arc driving magnetic flux, which is added to the increase in interrupting capability, it is important to design contact systems that are shaped in a way that heightens the density of the forward arc driving magnetic flux, due to the fact that arc driving magnetic flux formed by a grid system has many limitations.

If the formation of higher density is dependent on the shape of the contact system, although the interrupting current becomes higher at the same time as a result of the increase in interrupting capability, the strong forward arc driving magnetic flux can still easily be obtained. This is because the magnetic flux density is formed in proportion to the interrupting current flowing through the contacts.

Fig. 5 shows the shape of a stationary arc contact that is designed to obtain strong arc driving magnetic flux.

First, the newly designed stationary arc contact is a two cascading half-coil type to assure the wider distribution of forward arc driving magnetic flux within the contact system. In addition, the shape of the stationary arc contact has been designed to concentrate the forward arc driving magnetic flux within this distribution area, and to maintain the arc driving magnetic flux until the current is interrupted at zero, thus forcing the arc out as far as possible.

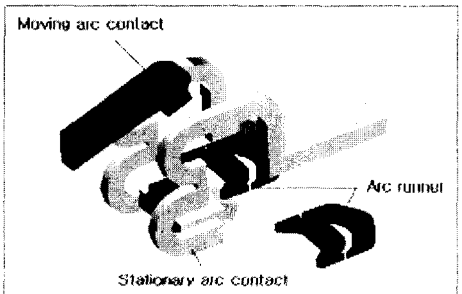


Fig. 5 Stationary arc contact for the newly developed strong arc driving magnetic flux

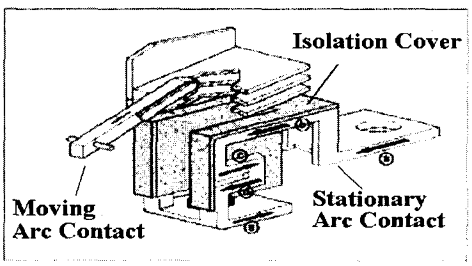


Fig. 6 Flow of the interrupting current in the contact system

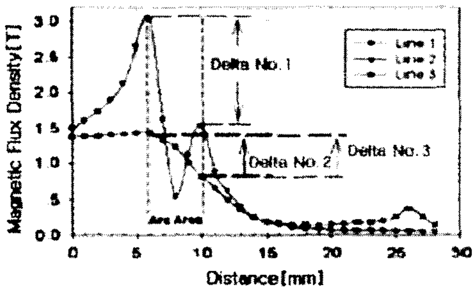


Fig. 7 Results of the magnetic flux density test on the newly developed model's arc driving magnetic flux

Second, the path of the interrupting current has been designed in the new contact system in a way that induces the interrupting current into the moving arc contact through a process of (a)→ (b)→ (c)→ (d)→(e), as seen in Fig. 6, while also assuring the co-electric absorption force and repulsive force between the two contacts.

In cases where the two contacts are in a closed state (on), which is the starting time of opening during the interrupting performance, the repulsive occurs because the current (e) and the current that passes the moving arc contact are flowing in opposite directions. This force is added to accelerate the speed of the opening operation of the moving arc contact. Moreover, the current of the moving arc contact at this time reacts with the absorption force of current (d), and plays the role of pulling the moving arc contact. As such, these two different forces induce a momentary high-speed opening of the moving arc contact.

Next, as mentioned in section 2.1, this study estimated and analyzed interrupting capability by conducting a 3-D magnetic investigation on the newly developed arc contacts. Fig. 7 indicates the results of the 3-D magnetic analysis conducted on the newly developed contact system.

According to Fig. 7, the newly designed model exhibits an improvement in interrupting capability efficiency of over 140% when compared with the MCCB manufactured by the M-company, which had been considered as having a high level of interrupting capability. The new model, which did not use a grid in the contact system, is shown in Fig. 5.

3. Interrupting characteristics test

3.1 Improvement of voltage recovery characteristics

3.1.1 Change in the shape of the arc runner

In general, success of the current interruption in a circuit breaker depends on two factors; one is the current interruption and the other is the voltage recovery characteristics. In this paragraph, the latter is described and focused on.

To improve the voltage recovery characteristics, this research changed the shape of the arc runner of the stationary arc contact in such a way that did not change the entire shape of the contact system, using the MCCB made by the sponsoring company as the basic model. The shape of the stationary arc contact of the basic model is displayed in Fig. 8, and the arc runner, which is a plane board type, is toward the terminal part of the stationary arc contact.

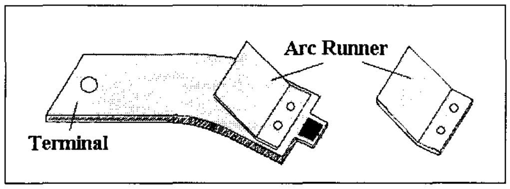
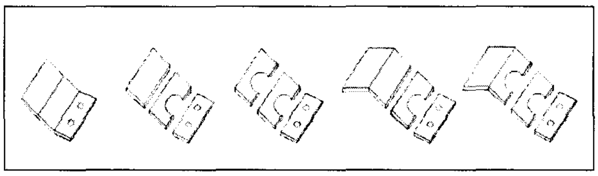


Fig. 8 Basic stationary arc contact and arc runner

As the shape of the arc runner in Fig. 8 forms an angle between the stationary arc contact and the floor, the arc runner serves as the pathway of the arc generated between the two contacts from the stationary arc contact when the moving arc contact initializes operation upon the signaling of the operative mechanism.

The arc runner extends the length of the arc and simultaneously pulls the arc away from the stationary arc contact and therefore increases interrupting capability.



(a) (b) (c) (d) (e)

(a) Basic arc runner, (b)~ (e) Changed arc runner (1)~(4)

Fig. 9 Model shapes of the arc runner on the stationary arc contact

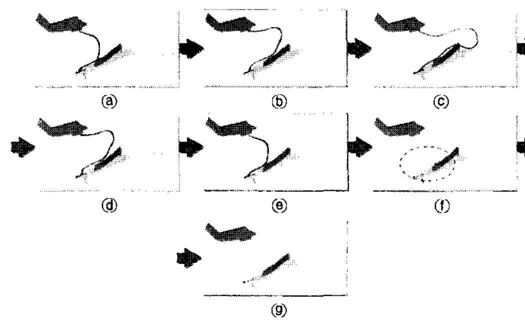


Fig. 10 Arc quenching process during current interruption

This research designed various arc runners, seen in Fig. 9, by separating the arc runner shown in Fig. 8 into three parts. As the fault current increases with time, an arc occurs between the two contacts. The arc under the arc driving magnetic flux generated by the grid moves to the outside of the contact system, following the arc runner, and extends from both of the contacts as demonstrated in Fig. 10. In cases where the fault current flows downwards toward current zero the arc driving magnetic flux by grid is decreased, thus weakening the strength of the arc driving force. After all, the remaining arc in Fig. 10 (f) is partially formed in the contact system as a result of Fig. 10 (g). When current zero occurs, the current path based on the remaining arc can easily be re-formed between the two contacts through the arc runner.

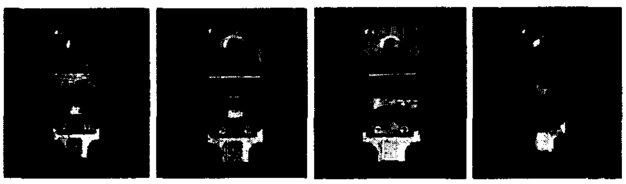
The formation of a current path often results in a failure to interrupt the fault current. By designing an arc runner that is separated into three parts, the voltage recovery characteristics between the two contacts can be improved.

At first, when the current remains at a high level, even if the runner becomes discontinuously connected, the arc is forced to the outside of the contact system due to the high level of current and strong arc driving magnetic flux.

In the case of low level of current over time, however, as a result of the weakening of the arc driving magnetic flux, the current path is suspended at the point of Fig. 10 (f) by the discontinuous arc runner. This result causes improvement in the voltage recovery characteristics.

The new shapes of arc runners, illustrated in Fig. 9 (b)~(e), were designed in a grid shape by cutting the middle of the arc runner into a U shape. This designing method is aimed at inducing Deion effects in order to strongly quench the arc occurring between the two contacts. Fig. 11 shows the real shapes of the contacts installed on the stationary arc contact.

In particular, the new arc runner (3) in Fig. 9 (d) is designed to be completely isolated from the stationary arc contact at the contact surface.

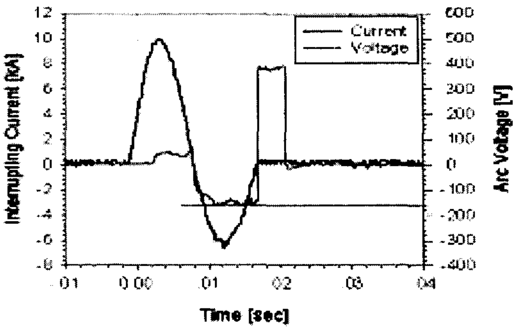


(a) (b) (c) (d)

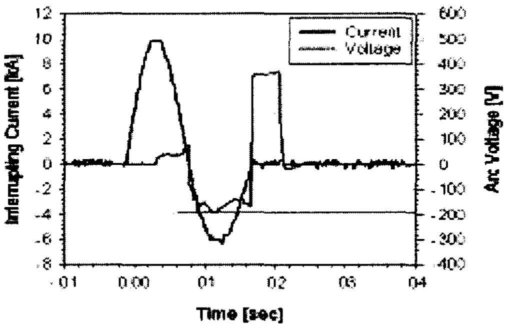
Fig. 11 Actual shapes of the newly designed arc runners

3.1.2 Voltage recovery characteristics system test

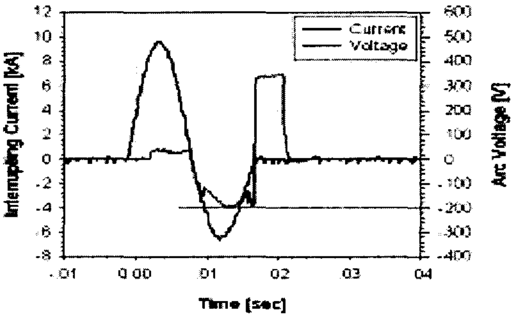
This research tested the voltage recovery characteristics of the MCCBs, using a Simplified Synthetic Testing Facility Using LC Resonant Circuit. The electric charger's interrupting current capacity was selected as 10kA. The condenser was charged at 1kV in order to provide the interrupting current. The condenser's 1kV of charger voltage becomes the voltage recovery right after current zero is reached once the interruption has occurred between the two contacts. Fig. 11 (a) shows the results of the test on the basic model.



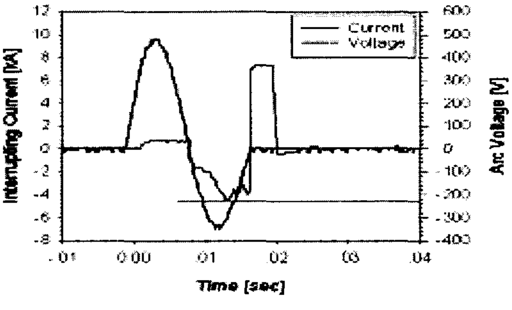
(a) Basic model contact system



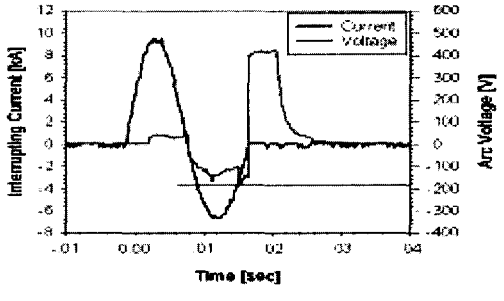
(b) Model contact system 1 (changed arc runner (1))



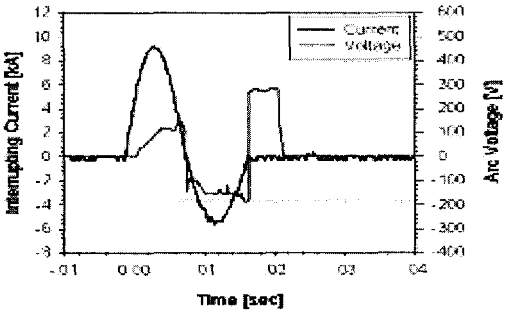
(c) Model contact system 2 (changed arc runner (2))



(d) Model contact system 3 (changed arc runner (3))



(e) Model contact system 4 (changed arc runner (4))



(f) Contact system manufactured by the L-company

Fig. 11 Results of the current interrupting test on the model contact systems

Fig. 11 (b), (c), (d), and (e) as mentioned in Section 3.1.1, are the results of the voltage recovery characteristics conducted on the model contact systems with newly developed stationary arc contacts brought about as a result of changes in the arc runner. Fig. 11 (f) analyzed the performance of the voltage recovery characteristics, testing the L-company's MCCB and comparing it with the isolation characteristics of the model contact system.

Based on the results of this test, the arc voltages of the contact systems, depending on the voltage used, can be summarized as follows:

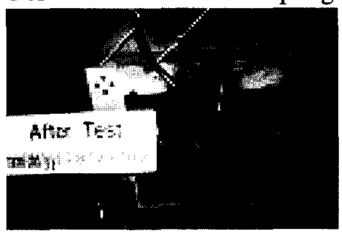
Model contact system 3(225V) > Model contact system 1, Model contact system 2(200V) > Model contact system 4, L-company(190V) > Basic model(155V)

As a result of the operation through which the arc was generated between the two contacts extending into the contract system; an increase in high arc voltage occurs when the arc resistance is increased. This results in a much higher interrupting capability. Based on these test results, the conclusion is reached that the stationary arc contact with the arc runner is more advantageous for interrupting capability. The reason for this conclusion revolves around the fact that the advanced stationary arc contact can create difficulties in building the current path owing to the remaining arc at current zero.

3.2 High power interrupting test

This paper used the results from the interrupting capability test and the voltage recovery characteristics test to carry out a current interrupting analysis on the new contact system seen in Fig. 5 in order to verify its interrupting capability. Fig. 12 exhibits the MCCB model before and after the current interrupting test. This research applied the O-t-CO test, which is the most in-depth of the current interrupting tests at conditions of 460V/35kA and 460V/50kA. Fig. 13 (a) shows the results of the current interrupting test at 460V/35kA and Fig. 13 (b) does the same at 460V/50kA.

(a) Before the current interrupting test

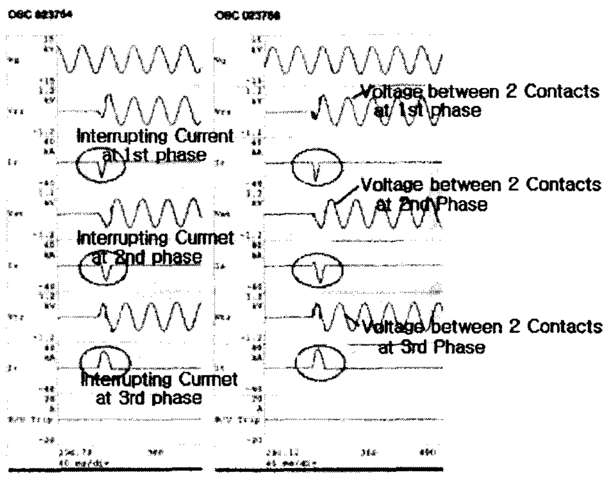


(b) After the current interrupting test

Fig. 12 Photos of the MCCB model before/after the current interrupting test

The test results indicate success; current limiting interruption.

As indicated in Fig. 13, the currents at each phase are limited and interrupted because the arc between two contacts is extinguished rapidly due to the strong magnetic drive force on it. And, following cancellation of the arc, the voltage at each phase is recovered fairly.



(a) 460V/35kA (b) 460V/50kA

Fig. 13 Results of the current interrupting test at 460V/35kA and 460V/50kA

4. Discussion

The following was carried out in this research:

i) In this paper, an analysis and estimation method to estimate the interrupting capability of MCCBs was developed, and the performances of various model MCCBs using the analysis and estimation method developed were examined.

As a result, it is certain that the interrupting capability increase is nearly proportional to the magnitude of the arc driving magnetic flux as indicated in Table 1.

ii) The researchers involved in this project designed a new shape for the arc runner of the stationary arc contact in the contact system, separating it into three parts in order to maintain the discontinuous current path. To verify the effect on the interrupting capability, current interrupting tests were carried out with a Simplified Synthetic Testing Facility Using LC Resonant Circuit.

Due to the discontinuous placement of the arc runner, which results in cutting down the current path between the two contacts immediately before/after reaching current zero, this paper concludes that the new shape of the arc runner has superior interrupting capability together with the improvement of the voltage recovery characteristics.

Eventually, it succeeded in carrying out a 460V/225A/35 kA current interrupting test on the newly designed contact system.

Therefore, this method of analyzing and estimating interrupting capability will increase the understanding of the performances of the newly developed MCCB and help achieve the optimal shape for the MCCB prior to the start of actual production. Moreover, this research investigated the possibility of improving the interrupting capability by applying a three-division cascading arc runner to the newly developed model MCCB. As such, based on the above contents, a 460/225A/50kA contact system with a current limiting molded case circuit breaker was developed for the first time in Korea.

References

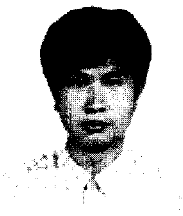
[1] Y.K.CHOI, T.G.KOO, K.S.LEE, "Development of contact system in 460V/225A/50kA MCCB", Journal of the Korea Institute of Illuminating and Electrical Installation Engineers, Vol. 16, No. 6, 2002, pp. 137-144.

[2] Mitsugu Takahashi, Takao Mitsuhashi, Yuuichi Wada, Sinji Yamagata, "Building up the arc driving magnetic flux in the contact system of MCCB", SP-95-56 published by Japanese Institute of Electrical Engineers, pp. 171-180.

[3] Special Issue, "New circuit breakers & Earth leakage Circuit Breakers", Mitsubishi Denki Giho, Vol. 69, No. 4, 1995.

[4] Takao Mitsuhashi, Mitsugu Takahashi,Yuuichi Wada, Sinji Yamagata, "Development of a new current limiting technique by 3D nonlinear analysis og magnetic fields in arc chambers and its application to L.V circuit breakers", SP-97-4 published by Japanese Institute of Electrical Engineers, pp. 15-20.

[5] Special Issue,"New MCCB, ELCB", Fuji Electric Journal, pp. 124-177, 1990.



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