J Electr Eng Technol.2018; 13(4): 1752-1758
http://doi.org/10.5370/JEET.2018.13.4.1752

ISSN(Print) 1975-0102
ISSN(Online) 2093-7423

# Implementing a Dielectric Recovery Strength Measuring System for Molded Case Circuit Breakers

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**Abstract** – In a low-voltage distribution system, the molded case circuit breaker (MCCB) is a widely used device to protect loads by interrupting over-current; however the hot gas generated from the arc discharge in the interrupting process depletes the dielectric recovery strength between electrodes and leads to re-ignition after current-zero. Even though the circuit breaker is ordinarily tripped and successfully interrupts the over-current, the re-ignition causes the over-current to flow to the load again, which carries over the failure interruption. Therefore, it is necessary to understand the dielectric recovery process and the dielectric recovery voltage of the MCCB. To determine these characteristics, a measuring system comprised of the experimental circuit and source is implemented to apply controllable recovery voltage and over-current. By changing the controllable recovery voltage, in this work, re-ignition is driven repeatedly to obtain the dielectric recovery voltage V-t curve, which is used to analyze the dielectric recovery strength of the MCCB. A measuring system and an evaluation technique for the dielectric recovery strength of the MCCB are described. By using this system and method, the measurement to find out the dielectric recovery characteristics after current-zero for ready-made products is done and it is confirmed that which internal structure of the MCCB affects the dielectric recovery characteristics.

**Keywords**: Dielectric recovery strength, Implementation of a measuring system, Molded case circuit breaker (MCCB), Current limitation effect

## 1. Introduction

Electric leakage accidents can occur from unknown causes. General causes of it include decrepit and faulty circuit breakers and shorts in the wiring, however, in spite of occasionally the circuit breaker is already tripped, the interruption isn't successful and may leads to an accident. In this case, there can be another cause, and we should consider that the main cause is re-ignition after current-zero.

When over-current flows, the trip unit of the MCCB detects it and separates the moving electrode from the fixed electrode. At that time, arc discharge occurs between two electrodes, and this arc is refracted by the Lorentz force and contact with the splitter plate. After the arc contacts the splitter plate, the arc voltage between electrodes increases and the over-current is restrained. This is referred to as the current limitation effect. Also, the splitter plate has a role to play in interrupting over-current to lengthen, separate, and cool the arc at current-zero. After current-zero, the over-current interruption is finished and the dielectric recovery strength between electrodes, which is reduced by the hot-gas generated by the arc, is restored again. In this dielectric recovery process, re-ignition means that the breakdown occurs again when the recovery voltage applied from the system power supply is higher than the dielectric recovery strength between electrodes. Through the re-ignition, the over-current flows to the loads again and the MCCB failure interruption.

Various studies have examined the dielectric recovery strength after current-zero [1-6]. Degui Chen et al. measured the dielectric recovery strength using a simplified splitter plate model and re-ignition process with changing current values and the depth of a splitter plate. They also describe the influence of various splitter plate configurations on the dielectric recovery voltage [7]. The dielectric recovery strength based on the influence of the arc chamber wall material has also been studied [8-10]. John J. Shea used an experimental arc chamber to approximate the MCCB and two independent circuits to apply the over-current and recovery voltage. The ablation was affected by the wall materials, which included alumina, polyamide, and polyoxymethylene, leading to various recovery voltages and pressure characteristics. [11]

In this paper, a measuring system is constructed to understand the dielectric recovery characteristics and re-ignition process for the MCCB with the current limitation effect. In the experiment, an existing MCCB is used for measurement. Chapter 2 illustrates the implementation of techniques used in a measuring system and the current limitation effect. The experiment results and analysis are described in Chapter 3. In Chapter 4, the results are

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Received: May 16, 2017; Accepted: February 5, 2018

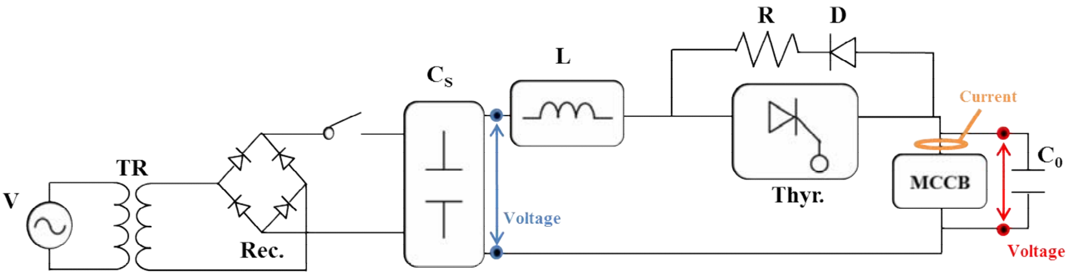


**Fig. 1.** Circuit used to measure the dielectric recovery voltage of the MCCB

discussed.

This study will investigate the characteristics of the dielectric recovery strength of the MCCB. It is expected that the clear analysis will elucidate the re-ignition phenomenon and effective preparations for electric leakage accidents involved in the MCCB.

## 2. Measurement System and Method

### 2.1 Experimant setup

To measure the dielectric recovery strength of the MCCB, the over-current, which operates the circuit breaker and controllable recovery voltage, are necessary. The measurement circuit is shown in Fig. 1.

While there are many other experimental circuits used to measure the dielectric recovery strength, we chose this circuit because it is simple and efficient [7].

In the circuit, V is a commercial power source (220V/60Hz), TR is the transformer, and Rec. is a full-bridge diode rectifier, and all three represent charging part.

$C_S$ is the capacitor bank and L is the inductor used to control the frequency of the over-current. Thyr. is a thyristor, $C_0$ is the capacitor for applying recovery voltage to MCCB, D is the diode, and R is the resistor. The voltage measurements consist of two points: one is between the voltage of $C_S$ and the other is MCCB and $C_0$. Current is measured with the Rogowski coil in front of the MCCB and it shows the over-current and arc current via re-ignition.

The capacitor bank $C_S$ consists of various capacities for producing several types of over-current. Each capacitor has the same voltage endurance of 450V and the $C_S$ can charge up to a maximum of 900 V by connecting it in series-parallel. Fig. 2 illustrates the connection of the capacitor bank.

The oscillating frequency of an over-current can be determined by $C_S$ and L. To make the desired frequency (60 Hz), the inductor L is produced using the cylindrical air-core coil [12]. The charging step consists of five stages. Table 2 shows the capacitance and inductance current values of each stage via charging at 640 V. Due to the existence of stray impedances in the circuit, a current value has some difference between the design and measured values.

**Table 1.** Values of each stage

| Stage | Capacitance [µF] | Inductance [mH] | Current [kA] |
|---|---|---|---|
| 1 | 4544.379 | 1.5483 | 0.6 |
| 2 | 10906.54 | 0.6451 | 1.2 |
| 3 | 17268.64 | 0.4074 | 2.9 |
| 4 | 27266.27 | 0.258 | 4 |
| 5 | 45443.79 | 0.1548 | 6.6 |

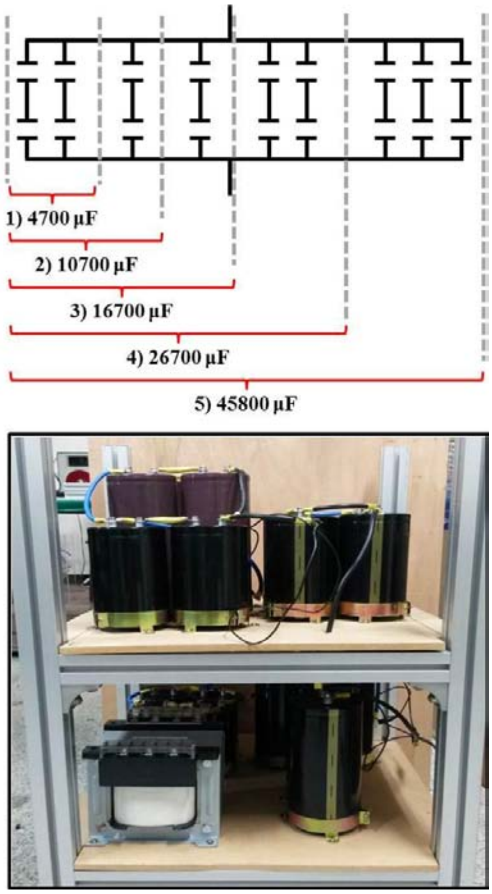


**Fig. 2.** Connection of the capacitor bank ($C_S$)

### 2.2 MeaSurement of dielectric recovery voltage

The measurement method of the dielectric recovery strength for the MCCB has the same principle as for other shapes of electrodes. For operating the circuit breaker, which separates the fixed electrodes and the moving

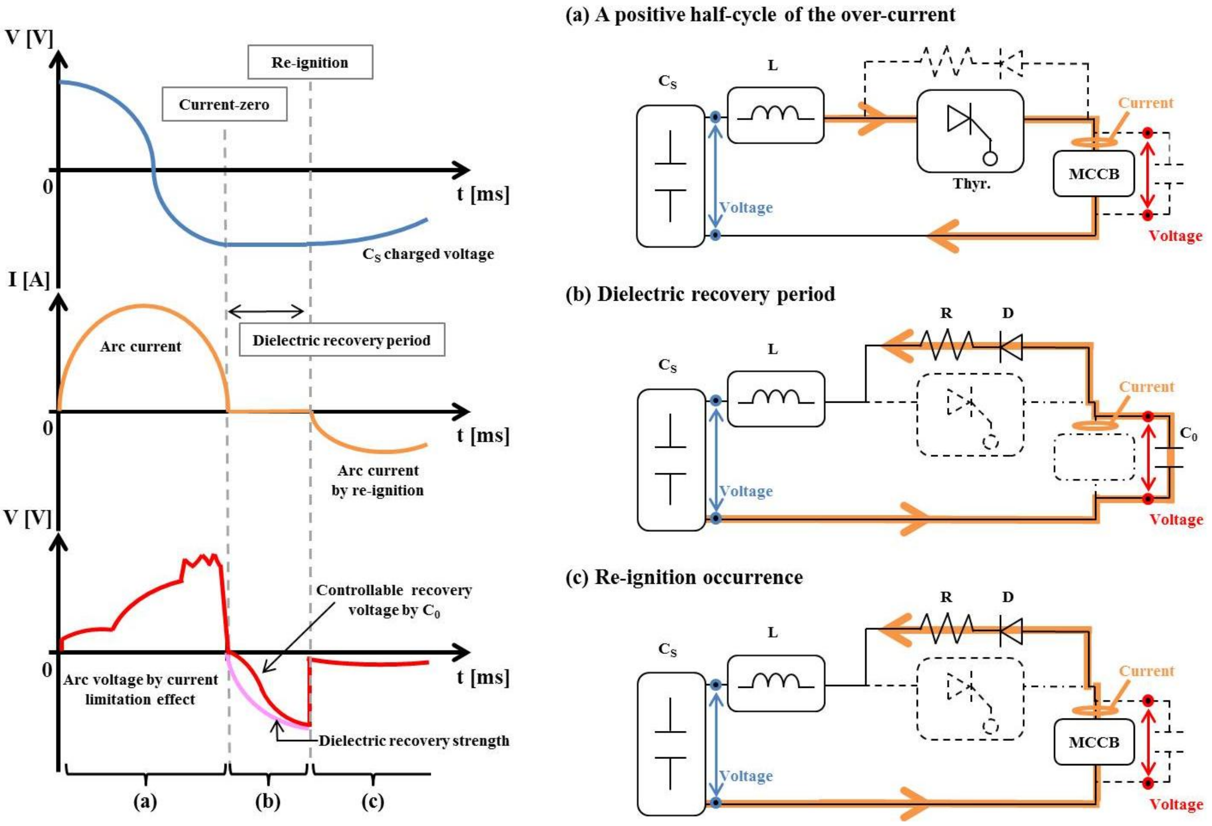


**Fig. 3.** Entire process to measure the dielectric recovery voltage. (a) A positive half-cycle of the over-current and (b) the dielectric recovery period (usually in micro seconds) and (c) the re-ignition occurrence

electrode, the over-current is needed. When it flows to the MCCB, arc current and arc voltage both occurred between the two electrodes in the arc extinguishing unit, and then the arc current becomes zero by interrupting the process with the current limitation effect of the circuit breaker. In the current-zero period, the controllable recovery voltage is needed for measuring the dielectric recovery voltage.

Fig. 3 describes the whole process from the over-current flow to the re-ignition occurrence for each process related to the circuit. The orange line represents a current flow at each circuit situation. When the trigger signal is input into Thyr., a positive half-cycle of the over current flows starting at MCCB, as shown in Fig. 3(a), and flows through $C_S$, L, Thyr., and MCCB in the circuit. The frequency of the over-current, which is 60 Hz, is decided by $C_S$ and L. The charged voltage $C_S$ starts to discharge and an arc voltage is applied between the electrodes. There is some difference between the arc voltage compared with the simple electrode structures; due to the current limitation effect of the splitter plate, the arc voltage increases rapidly when the arc contacts the splitter plate.

Next, the dielectric recovery period after current-zero is shown in Fig. 3(b). In this period, a current flow through $C_S$, $C_0$, D, R, and L, in that order, and $C_0$ is charged to apply a recovery voltage to the MCCB. The charging speed of $C_0$ is determined by $C_0$ and R. Therefore, by changing the capacity of $C_0$, the recovery voltage can be controlled.

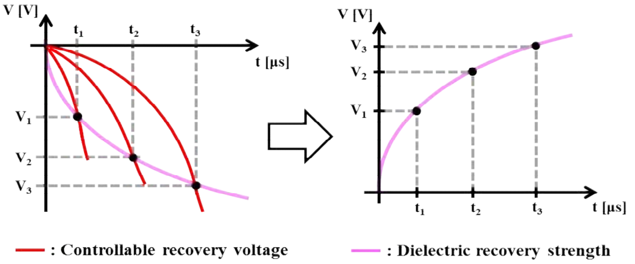


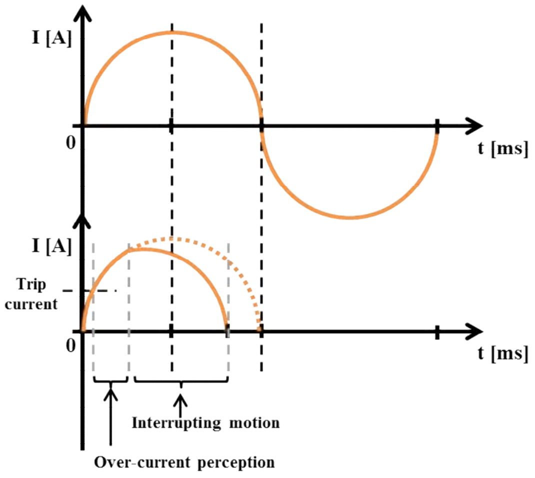
**Fig. 4.** Measurement method of the dielectric recovery voltage

To find out the unknown dielectric recovery strength of the MCCB, re-ignition is initiated on purpose by maintaining the dielectric recovery strength and controllable recovery voltage. When re-ignition occurs, as shown in Fig. 3(c), a current flow through $C_S$, MCCB, D, and R, in that order.

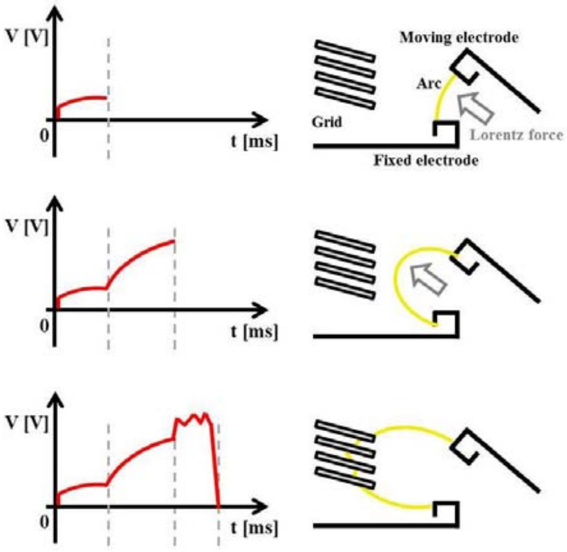
As previously stated, the measurement method of the dielectric recovery voltage, which changes with the gradient of $C_0$, i.e., the charge speed, is illustrated in Fig. 4. Therefore, the dielectric recovery voltage can be measured via repetitive experiments.

## 2.3 Current limitation effect

The current limitation effect is one of the special characteristics of the MCCB. As mentioned above, this



(a) A current waveform



(b) Process of the increasing the arc voltage

**Fig. 5.** Schematics of the current limitation effect

effect is a result of the splitter plate structure. The shape, number, and size of the splitter plate varies according to the manufacturer; however, a basic principle is as follows: Fig. 5 illustrates the generation process of the current limitation effect and resultant waveform of the limited current.

When the over-current with a frequency reaches the trip current values of the MCCB, as shown in Fig. 5(a), the trip unit of the MCCB perceives this and begins the interrupting motion that separates the moving electrodes from fixed electrodes.

After the interrupting motion begins, the arc occurs between two electrodes and applies a low arc voltage before reaching the splitter plate. Then, the arc is bent by the Lorentz force to the splitter plate and the arc voltage between the electrodes increases with the arc length. When the arc reaches the splitter plate, the arc voltage is rapidly increased. And then the arc voltage fluctuates and goes to zero with an extinction of the arc. As a result, the frequency of the over-current gets shorter than the original frequency through these processes, and it also shortens the current-zero to a point. This leads to increased interrupting performance.

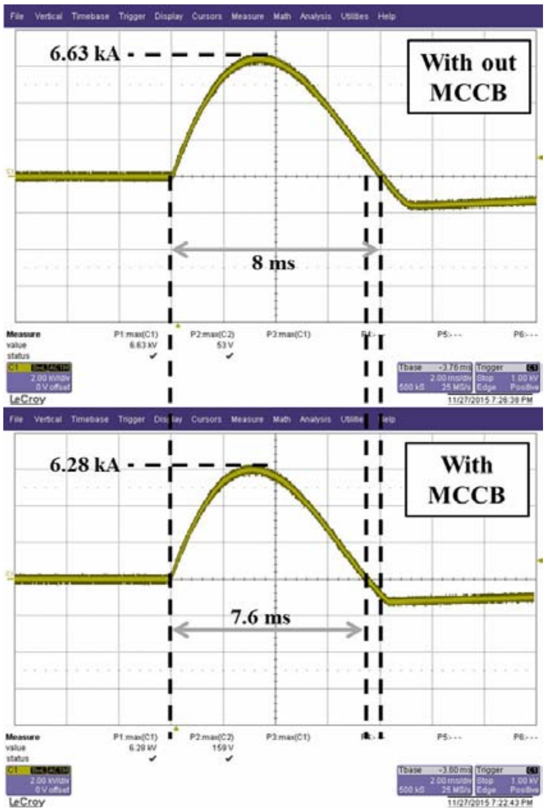


**Fig. 6.** Current wave form with/without the current limitation effect of the MCCB

As the Lorentz force is proportional to the amplitude of the current, the arc contacts the splitter plate more by increasing the over-current. Therefore, the current limitation effect becomes stronger.

Fig. 6 shows the effect of current limitation when the over-current, which has a peak current value of 6.6 kA and 60 Hz (Stage 5), flows to it. As a result of this effect, the maximum value decreases and the current-zero point is shorter than in the case without the MCCB.

## 3. Experiment Results

### 3.1 Results according to current magnitude

The MCCB used in this experiment is the UCB 100 S model manufactured by Hyundai heavy industries. This device has 125 AF and the rate current is 50 A. The experiments are done according to current magnitude.

Fig. 7 shows the process of the dielectric recovery voltage. After the current-zero point, the dielectric recovery period begins and re-ignition occurs via the controllable recovery voltage. The dielectric recovery voltage is shown

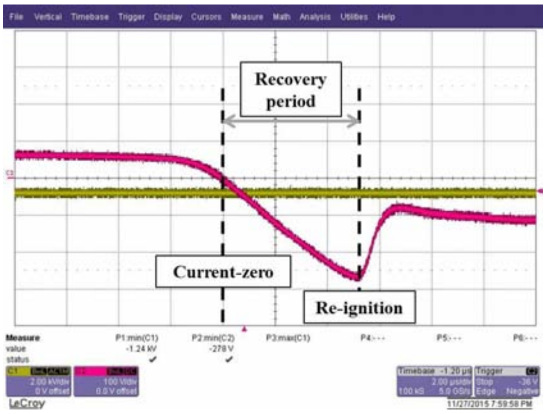


**Fig. 7.** Waveform measuring the dielectric recovery voltage

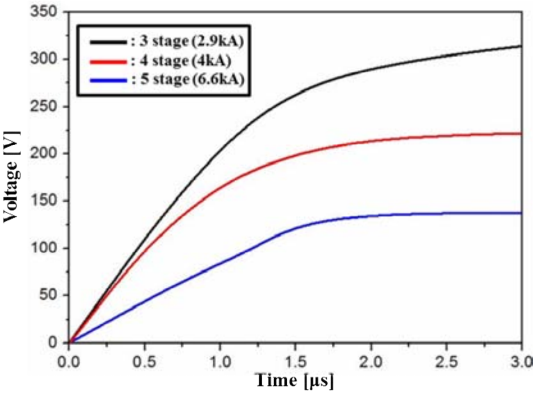


**Fig. 8.** Dielectric recovery voltage of each stage current value

in Fig. 8 by changing the current magnitude. As the current increases, the dielectric recovery voltage between electrodes decreases.

It seems that the high magnitude current creates more hot gas in the interruption unit and these hot gas results in weaker dielectric recovery strength. Therefore, because the high magnitude current flow when an accident occurs, it is necessary to find out which structure in the MCCB affects the dielectric recovery characteristics for improving the interruption performance after current-zero. In the case of lower current values such as stage 1 (0.6 kA) and stage 2 (1.2 kA), the MCCB did not work. It is thought that the current was not strong enough to operate the MCCB over a short period of time.

### 3.2 Results according to product type

As above mentioned, the basic principle of interruption operation for the MCCB is similar to per manufacturer, however, the shape and number and size of splitter plate have some difference. Also, the internal structure of arc extinguishing unit has difference, too. Therefore, the experiment according to product type are done applying the dielectric recovery voltage measuring method.

Fig. 9 shows the products used in experiment. (a) is UCB 100 S model manufactured by Hyundai heavy industries and (b) is ABS 193c model manufactured by LS industrial system and (c) is EZC 100 H model manufactured by Schneider electric. All product has similar specifications such as AF and rate current.


(a) (b) (c)

**Fig. 9.** The products used in experiment

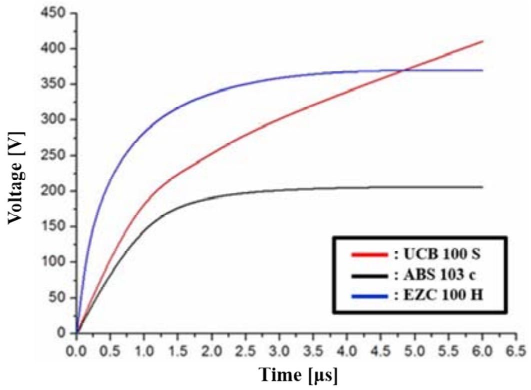
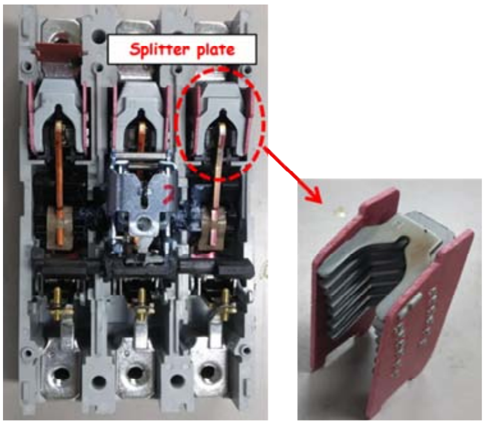


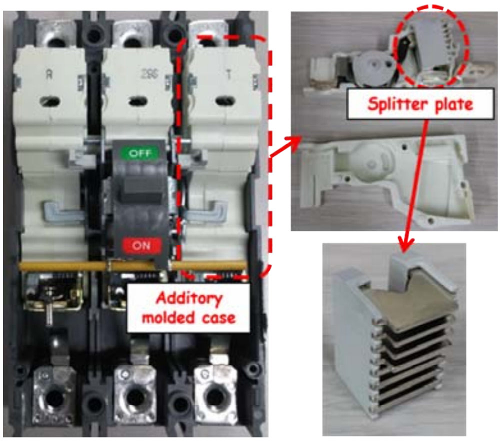
**Fig. 10.** Dielectric recovery voltage of each product in stage 4 (4 kA)

Fig. 10 shows the dielectric recovery voltage of each product applying stage 4 power source (4 kA). As a result, the initial dielectric recovery, which means initial cooling ability of residual hot-has, is EZC 100 H excellent due to the high dielectric strength is recovered for a short time initially as shown in the graph. And the dielectric recovery after time, which means whether exhaust of hot-gas is easy or not, is UCB 100 S excellent because the highest dielectric strength in recovered over time.

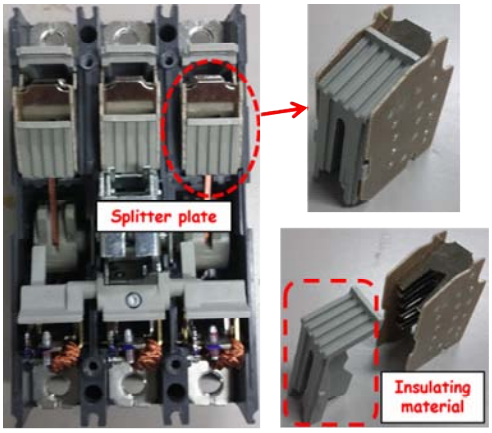
To analyze the causes of these results, the internal structure and splitter plate of each product is compared and analyzed. Fig. 11 shows internal structure and splitter plate of each product. In case of UCB 100 S, it has large exhaust port for easy exhaust of residual hot-gas and no additional structure between electrodes and splitter plate. Next, ABS 100 c has exhaust too however, it is small and electrodes and splitter plate are surrounded in the additional molded case. Therefore, the exhaust speed of residual hot-gas and dielectric strength does not increase greatly. Finally, EZC 100 H is excellent the initial dielectric recovery compared to other products. It because easy exhaust of residual hot-gas through large exhaust port. Also, the



(a) UCB 100 S



(b) ABS 103 c



(c) EZC 100 H

**Fig. 11.** Internal structure of arc extinguishing unit and splitter plate of each product

installed insulating material on splitter plate effects on cooling of residual hot-gas.

## 4. Conclusion

This paper describes a measurement system and method of dielectric recovery strength for a molded case circuit breaker. Also, measurement and analysis for product type are done by using these system and method. To measure the dielectric recovery strength of the MCCB, both the over-current, which operates the circuit breaker, and the controllable recovery voltage, which occurs at optional re-ignition, are necessary. Therefore, an effective circuit satisfying these requirements is implemented and the relationship between dielectric recovery characteristics and internal structure of the MCCB is analyzed through measurement experiments on ready-made products.

As shown in experiment results, in order to recover the initial fast dielectric strength, a structure that helps cooling the residual hot-gas is required such as insulating material. Also, a space between the electrode and the exhaust port is advantageous for easy exhaust of the residual hot-gas, which recover the high dielectric strength over time. As a result of these presented measurement results, we plan to design an appraisal standard of the dielectric recovery strength of the MCCB. These developments can also be considered during future designs to increase interruption performance.

Measurements taken with repetitive experiments are time consuming and costly. For economic and efficiency reasons, research, simulations or circuit models of this phenomenon are needed for future research.

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