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RESEARCH ARTICLE

# Insulation Resistance and Tracking Index of Circuit Breaker According to the Accelerated Aging Test

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**ABSTRACT** This study examined insulation resistance and tracking index characteristics through the accelerated aging test of low-voltage circuit breakers. The leakage current was found to be influenced by external factors rather than the internal structure. Additionally, the insulation resistance of the circuit breakers undergoing accelerated degradation was measured using a Megger insulation tester. In the case of a circuit breaker manufactured using the accelerated aging test, the insulation resistance increased compared to that of a circuit breaker under normal conditions. However, the insulation resistance of aged circuit breakers collected from various regions of Korea exhibited a decrease in correlation with their equivalent lifetimes. The tracking test of the circuit breaker was conducted in accordance with IEC 60112. In the case of a circuit breaker under normal conditions, tracking did not occur even at an applied voltage of 400 V. Furthermore, no tracking was observed in the circuit breaker manufactured through the accelerated aging test. However, for the aged circuit breakers collected from various regions in Korea, tracking occurred even at an applied voltage of 125 V. Consequently, upon analyzing the circuit breaker components in relation to degradation, it was observed that, as degradation advanced, certain components were lost, and in the case of aged circuit breakers, the characteristics of the insulator were also compromised.

**INDEX TERMS** Accelerated aging test, Arrhenius equation, CTI, circuit breaker degradation, circuit breaker lifetime, FT-IR, insulation resistance.

## I. INTRODUCTION

Circuit breakers are vital devices used in many distribution systems to protect against faults in power systems. They are classified into different types depending on the location and capacity of the application, including vacuum circuit breakers, oil circuit breakers, air circuit breakers, miniature circuit breakers (MCBs), and residual current device (RCD). Generally, MCBs and RCDs are used in low-voltage indoor power systems [1], [2]. However, persistent fires are occurring in distribution systems, and when examining the statistics of electrical fires, it becomes evident that a significant proportion of them originates in low-voltage distribution panels. Therefore, this study has been conducted to analyze the fire risk associated with low-voltage circuit breakers.

An MCBs is mainly used to interrupt overcurrent and as the main circuit breaker in a distribution panel. The overcurrent blocking operation method of an MCBs uses a bimetal and plunger mechanism. The bimetal is composed of two metals with different thermal expansion characteristics, and as it heats up, it undergoes deformation or deflection. The electrical current generates heat. When overcurrent flows through a circuit breaker, it leads to heating, which causes deformation of the bimetallic strip. Furthermore, as the magnitude of the overcurrent increases, it results in a reduced tripping time characteristic. The plunger method uses an electromagnet with a winding that is in series with the load current. When

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a short circuit occurs, the current flowing through the circuit conductor increases the field strength of the electromagnet and attracts the armature. In this case, the armature rotates the trip bar, causing the RCD to trip [3].

An RCD is used in low-voltage circuits to provide electric shock protection and prevent fires caused by leakage current. There are two types of trip mechanisms for an RCD: the electronic trip type and the zero-phase current transformer (ZCT) trip type. The electronic trip type detects and amplifies the leakage current from the ZCT output using an electronic circuit and then transmits a trip signal to the RCD trip coil. The ZCT type receives the leakage current and amplifies it based on the turn ratio of its own winding, without the use of an electronic circuit, to directly actuate the trip bar of the RCD [4].

MCBs and RCDs are standardized in terms of their application range, rating, and structure according to IEC 60947-2, 61008-1, and 61009-1. They are designed and manufactured to comply with these standards. However, this highlights the limitation that reliability, which is used to evaluate performance during use, is not considered [1], [2].

In Korea, many power facilities were installed from the 1980s to 1990s due to rapid industrialization, resulting in a high demand for circuit breakers to ensure a safe power supply. According to circuit breaker manufacturers, the life expectancy of low-voltage circuit breakers is 20 years. However, only a few companies have provided quantitative data on the degradation of low-voltage circuit breaker over time. The degradation of circuit breakers is caused by internal and external factors in the environment in which they are used, which can result in short circuits and tracking and can ultimately lead to fire accidents.

We reviewed studies on the replacement cycle and life evaluation of low-voltage circuit breakers in Korea. For example, Lee [5] conducted performance tests on MCBs that had been in use for over 20 years and observed phenomena such as failures in the operation test, increased temperature beyond the standard, and breakdown of the switchgear operating spring. Kim et al. [6] by collecting and evaluating the operational characteristics of the RCDs in use based on the period of use, a failure rate of 50% was observed within a lifetime of approximately 10 years. Accordingly, the "IEEE_0493_2007 Gold Design of Reliable Industrial and Commercial Power System" proposes the life expectancy of major electrical devices. The proposed life expectancy for MCBs is 20 years, while that for RCDs is 15–20 years [7]. However, this criterion is limited because it was studied by applying only mean time to failure and failure mode, effects, and criticality analysis methods according to the probability and statistical failure rate [8]. As it turns out, there are no ongoing studies that can analyze degradation from the engineering aspect based on the use environment of circuit breakers and suggest replacement cycles through life evaluation [9], [10], [11].

In this paper, we highlight the importance of considering not only the failure rate but also the insulation characteristics in the life evaluation of circuit breakers, considering their use environment. MCBs and RCDs have different internal operating structures, but the insulation structure is the same, and the insulation component is identified as phenolic resin. There are four causes of degradation of phenolic resin [12], [13], [14], [15]:

- Thermal degradation: The increase in temperature amplifies intramolecular vibrations and accelerates conformational changes in macromolecules.
- Electrical degradation: In a typical electrical degradation, transient voltage and surge current cause partial discharge, electric tree, and water tree phenomena.
- Photochemical degradation: In a typical photochemical degradation, depending on the photon energy, radiation may electronically excite and thus make some groups reactive in the polymer.
- Oxidative degradation: Oxidative degradation is a chemical process in which a substance breaks down due to its interaction with oxygen or other oxidizing agents.

The degradation rates of the abovementioned factors vary depending on the use environment of the low-voltage circuit breaker. In the case of outdoor distribution panels, unlike indoor distribution panels, there is a higher likelihood of direct exposure to sunlight or exposure to oxidizing agents other than oxygen. This suggests that photochemical and oxidative degradation rates may vary depending on the installation environment of low-voltage circuit breakers. This is because electrical degradation occurs as an internal factor, while photochemical and oxidative degradation occur as external factors. In particular, thermal degradation is affected by the internal heat generated by the current and external radiant heat. Accordingly, we studied the degradation characteristics by measuring the insulation resistance and the comparative tracking index (CTI) of the circuit breaker in relation to thermal degradation.

Insulation resistance is a quantitative physical quantity used to determine the degradation of the insulator in an electrical device. When a direct current (DC) voltage is applied to an insulator, the instantaneous charging current increases rapidly. Charging current gradually decreases through the absorption current, and when it reaches a constant value, only leakage current flows. Insulation resistance is measured by dividing the applied voltage by the leakage current obtained after applying the DC voltage to the insulator.

The CTI is used to evaluate the tracking properties of an insulator [16]. Tracking refers to an electrical breakdown that occurs on the surface of an insulator. In this process, exposure to electrical arcing generates heat and carbonizes the material, as shown in Figure 1. Dust, salt fog, water, and other substances can form a layer on the insulator. When combined with moisture in the atmosphere, this layer becomes conductive, allowing the current to flow through it. The carbonized areas exhibit higher conductivity compared to the original insulator, resulting in increased current flow and subsequent heating. This process eventually renders the insulator fully conductive. When the

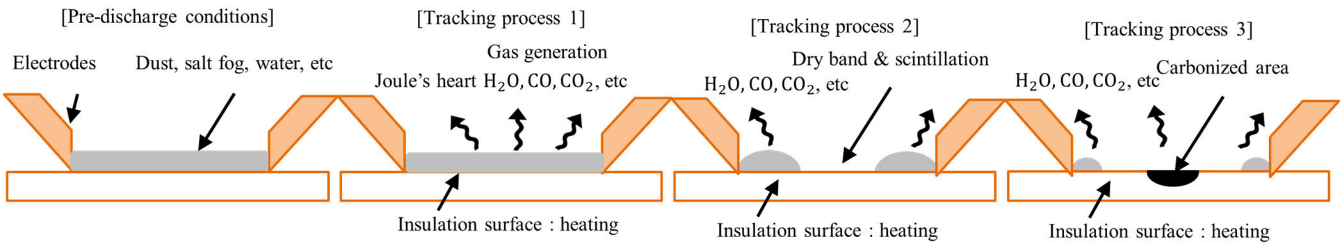



**FIGURE 1.** Mechanism of tracking phenomenon.

**TABLE 1.** Insulating material group according to the CTI.

| Insulating material group | CTI |
|---|---|
| I | 600 ≤ CTI |
| II | 400 ≤ CTI ≥ 600 |
| IIIa | 175 ≤ CTI ≥ 400 |
| IIIb | 100 ≤ CTI ≥ 175 |

current finds a carbonized conductive path to the ground or another energized conductor, tracking can lead to a flashover event.

IEC 60112:2020 specifies the test method for determining the proof and comparative tracking indices of solid insulating materials. Furthermore, IEC 60601 classifies the insulation class based on the CTI, as illustrated in Table 1 [17].

## II. ACCELERATED AGING TEST

### A. ACCELERATED AGING TEST OF LOW-VOLTAGE CIRCUIT BREAKERS

To analyze the insulation characteristics of circuit breakers under degradation, an accelerated aging test was conducted. This test aimed to evaluate the lifespan of power equipment by applying stress artificially.

Acceleration testing involves subjecting materials or products to stressors such as temperature, voltage, and vibration at their maximum or limit values. According to the IEC 62506 Standard on Methods for Product Accelerated Testing, acceleration testing is categorized into quality and reliability acceleration tests [18]. Quality acceleration tests are used to identify product limitations and design defects by inducing faults. In contrast, reliability acceleration testing applies stress for a short duration to estimate the product's lifespan. It also involves quantifying failure data, fault distribution, and the frequency of failures. Furthermore, reliability accelerated tests can be classified into two categories: accelerated life tests and accelerated aging tests. An accelerated life test is used to identify the causes of failure, while an accelerated aging test focuses on measuring the properties of a material rather than its failure. Therefore, an accelerated aging test should be used for the insulators of circuit breakers, where the concept of failure is not clearly defined. The lifetime-stress equation adopted in an accelerated aging test incorporates various models, such as the Arrhenius model, inverse power law model, and Eyring model [19], [20].

The accelerated aging tests of low-voltage circuit breakers have been investigated using the Arrhenius equation. The Arrhenius equation is an empirical law for describing the temperature dependence of chemical reaction rates, as shown in Equation (1).

$$\tau = A \cdot exp(-\frac{E}{K} \cdot T) \quad (1)$$

This expresses degradation according to time and temperature, as shown in Equation (2) [21], [22].

$$K_2 = K_1 \cdot \exp\left[\frac{E_a}{K_b} \cdot \left(\frac{1}{T_2} - \frac{1}{T_1}\right)\right] \quad (2)$$

where $K_1$ is the accelerated degradation time, $K_2$ is the equivalent life, $K_b$ is the Boltzmann constant, and $E_a$ is the activation energy. Activation energy is an important index for setting acceleration degradation times. In this study, the activation energy of 0.77 eV was used by referring to the paper that calculated the activation energy through the permittivity of phenolic resin, which is a component of the circuit breaker enclosure [23]. Accelerated degradation time can vary depending on the temperature used for accelerated degradation. When operating at low temperatures, reliability can be enhanced compared to that at high temperatures. However, accelerated degradation time may also increase irreversibly. Based on the heat distortion temperature of phenolic resin, an accelerated degradation temperature ($T_1$) of 130°C was selected. During accelerated aging tests, conducting experiments at lower temperatures is generally considered to enhance reliability. However, in the case of the insulation material of the circuit breakers used in this study, no significant changes in insulation performance were observed even at temperatures below 100°C. Therefore, an accelerated aging temperature of 130°C, which closely approximates the glass transition temperature of the phenolic resin, was chosen for our experiments. Additionally, $T_2$ represents the temperature commonly used in low-voltage circuit breakers, which is 40°C, the maximum safety temperature employed in low-voltage distribution boards. Table 2 provides the accelerated degradation times required to manufacture low-voltage circuit breakers with equivalent lifespans of 10, 20, 30, and 40 years. The

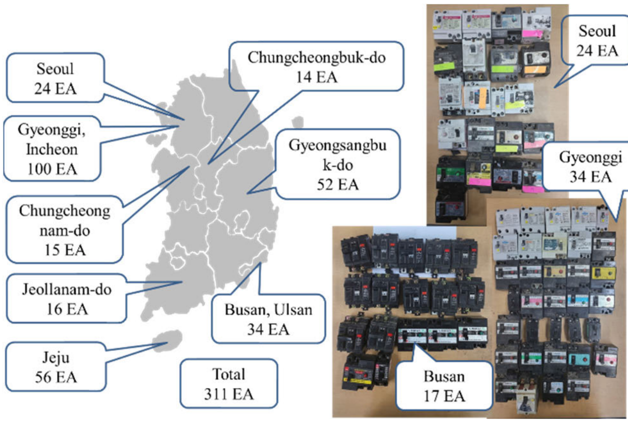



**FIGURE 2.** Aged circuit breakers collected from all parts of Korea.

**TABLE 2.** Accelerated degradation time calculated through the Arrhenius equation.

| $K_2$ : Equivalent life | $K_1$ : Accelerated degradation time |
|---|---|
| 10 years | 110 hour |
| 20 years | 220 hour |
| 30 years | 330 hour |
| 40 years | 440 hour |

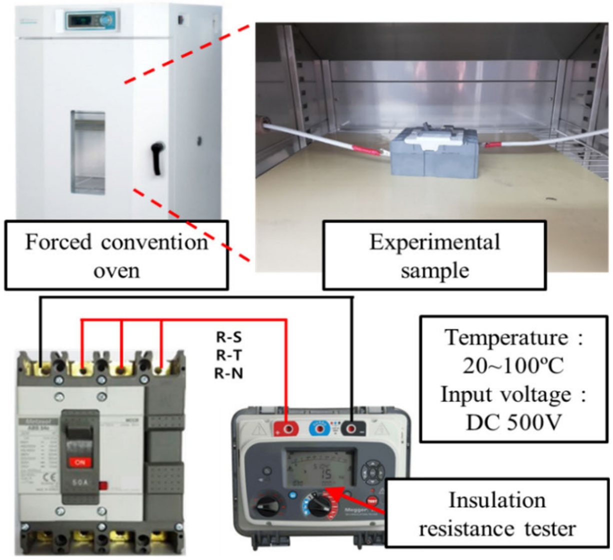



**FIGURE 3.** Experimental setup for insulation resistance of the circuit breaker.

**TABLE 3.** Failure rate of aged circuit breakers according to the date of manufacture.

| Date of manufacture | Failure rate |
|---|---|
| 1980s | 10EA/16EA (62%) |
| 1990s | 68EA/110EA (62%) |
| 2000s | 29EA/63EA (46%) |
| 2010s | 29EA/72EA (40%) |
| 2020s | 5EA/14EA (35%) |
| Unconfirmed | 18EA/36EA |

stress was applied using a constant stress accelerated test method. A circuit breaker sample was then produced using the corresponding accelerated degradation time specified in Table 2. Furthermore, the insulation resistance and CTI of the manufactured circuit breaker were measured and compared with those of a circuit breaker used in a real-world environment.

### *B. OPERATING CHARACTERISTICS OF LOW-VOLTAGE CIRCUIT BREAKERS USED IN A REAL ENVIRONMENT*

Circuit breakers exhibit varying degradation characteristics depending on the installation environment. Therefore, from a statistical perspective, we collected aged circuit breakers from various locations throughout South Korea to analyze the insulation properties of circuit breakers used in real-world environments. The number of circuit breakers collected is depicted in Figure 2. Furthermore, the collected aged circuit breakers were classified based on their manufacturing dates, and the failure rate was analyzed according to the equivalent lifetime.

The collected aged circuit breakers were RCDs. Their failure rate was determined by testing whether or not they tripped when an electrical leakage occurred, using an earth leakage tester.

Table 3 displays the failure rates of aged circuit breakers based on their manufacturing dates. For circuit breakers manufactured in the 1980s and 1990s, the failure rate was 62%, indicating that more than half of these experienced failures. However, the circuit breakers manufactured in the 2000s had a failure rate of 46%, those manufactured in the 2010s had a rate of 40%, and those from the 2020s had a rate of 35%. This implies that as the equivalent lifespan of a circuit breaker increases, the failure rate also increases. Additionally, a circuit breaker that has deteriorated for more than 20 years cannot maintain its functionality.

The operating characteristics of the aged circuit breakers collected from various locations across the country yielded results consistent with the equivalent lifespan of low-voltage circuit breakers outlined in the "IEEE_0493_2007 Gold Design of Reliable Industrial and Commercial Power System." This confirms the reliability of the collected breakers, as determined by the author.

## III. INSULATION RESISTANCE OF LOW-VOLTAGE CIRCUIT BREAKERS ACCORDING TO THE DEGRADATION

### *A. EXPERIMENTAL SETUP ACCORDING TO THE INSULATION RESISTANCE OF LOW-VOLTAGE CIRCUIT BREAKERS*

The insulation resistance measurement of a circuit breaker is used to detect leakage, and the Korea Electro-technical Code mandates the measurement of insulation resistance between the ground and the circuit breaker terminals. However, this method is inadequate for evaluating the fire risk associated

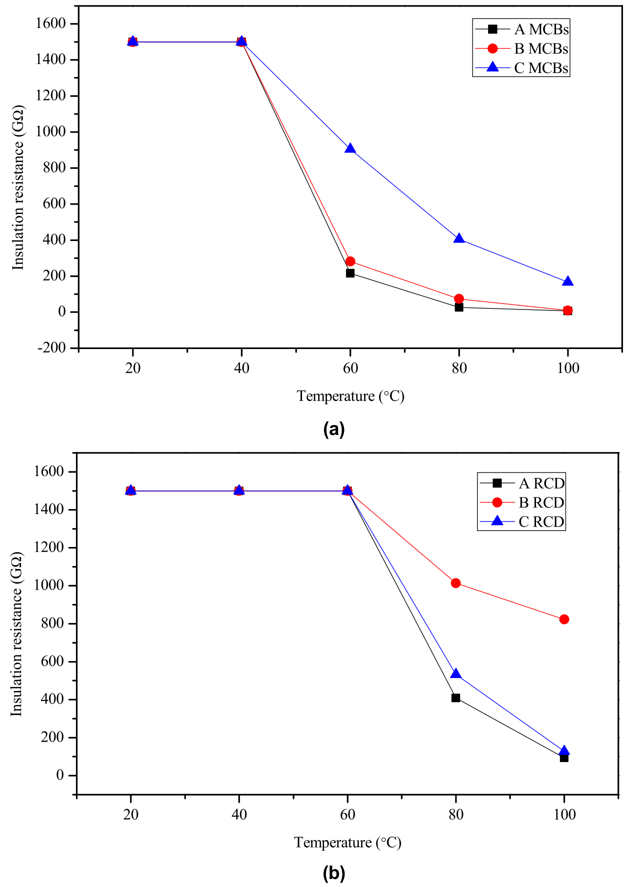



**FIGURE 4.** **Insulation resistance according to the temperature of circuit breaker. (a) MCCB (b) ELCB.**

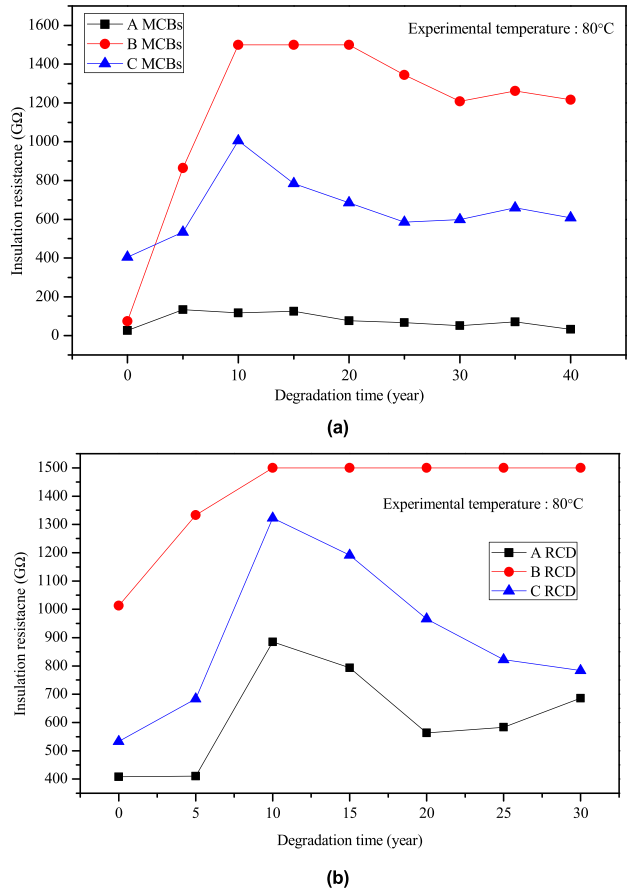



**FIGURE 5.** **Insulation resistance according to the degradation time of circuit breaker. (a) MCCB (b) RCD.**

with tracking and insulation degradation. Therefore, in this study, the fire risk was assessed by measuring the insulation resistance between the phases of the circuit breaker.

Figure 3 depicts the hardware configuration used to measure the insulation resistance of circuit breakers. The average values from the three test runs were used to obtain the results. To maintain the circuit breaker's temperature, a forced convection oven was used, and the experiment was conducted at 20°C, 40°C, 60°C, 80°C, and 100°C. Additionally, insulation resistance was measured using a Megger S1-1568 instrument under an applied DC voltage of 500 V in accordance with the IEC 60947-2 (Low-voltage switchgear and controlgear - Part 2: Circuit-breakers) international standard [24].

### *B. EXPERIMENTAL RESULT ACCORDING TO THE INSULATION RESISTANCE OF LOW-VOLTAGE CIRCUIT BREAKERS*

Initially, three circuit breaker manufacturers (A, B, and C) were chosen to assess the insulation resistance of circuit breakers under normal conditions. Subsequently, insulation resistance was measured at different temperatures of the circuit breaker; the results are depicted in Figure 4.

Fig. 4 (a) displays the insulation resistance of an MCBs as a function of temperature. At room temperature, none of the circuit breakers exhibited leakage current, resulting in the highest measured insulation resistance. The same outcome was observed at the experimental temperature of 40°. However, the insulation resistance of the circuit breakers decreased at 60° and, subsequently, exhibited a decreasing trend as the temperature increased.

Figure 4 (b) depicts the insulation resistance of an RCD as a function of temperature. No leakage current was observed at the experimental temperature of 60°C, resulting in the highest measured insulation resistance. Furthermore, the insulation resistance of the RCD exceeded that of the MCBs under the same temperature conditions. This result is attributable to the difference in separation distance between the phases of the MCBs (8 mm) and RCD (14 mm). The shorter separation distance in the MCBs is likely to facilitate leakage current conduction through the surface of each phase rather than through the internal structure.

Figure 5 presents the insulation resistance of the circuit breaker manufactured through the accelerated aging test. The test was conducted on the circuit breaker until it reached an equivalent lifetime of 40 years, with insulation resistance measurements taken every 5 years of the equivalent lifetime.

Figure 5 (a) depicts the insulation resistance of the MCBs over the degradation time. Despite undergoing accelerated aging testing, the circuit breakers exhibited maximum insulation resistance values under the experimental conditions of 60°C or lower. Therefore, the alteration in insulation resistance based on the equivalent lifetime was analyzed under the experimental condition of 80°C. In the case of MCBs A, the change in insulation resistance was negligible despite the increase in acceleration time. However, MCBs B and C exhibited the highest insulation resistance at 10 years of equivalent lifetime. Notably, the insulation resistance of MCBs B was measured at its maximum value, indicating an improvement in insulation performance despite the accelerated aging test. In the case of an equivalent life of 30–40 years, the insulation resistance showed a tendency to decrease as the equivalent lifetime increased. However, the insulation resistance remained higher compared to a circuit breaker under normal conditions without accelerated degradation.

Figure 5 (b) illustrates the insulation resistance of the RCD as a function of degradation time. Similar to the MCBs, the RCD also exhibited changes in insulation resistance according to the equivalent lifetime. However, the insulation resistance characteristics were comparable between the MCBs and RCD. Therefore, a comparative analysis was conducted between the insulation resistance of the circuit breaker manufactured through accelerated aging testing and that of aged circuit breakers to understand the factors contributing to increased insulation resistance.

The aged circuit breakers were classified based on their date of manufacture, and Figure 6 displays the corresponding insulation resistance of these breakers. The insulation resistance of the low-voltage circuit breaker decreased with increasing equivalent life. In particular, circuit breakers manufactured in the 1990s and 2000s showed a rapid decrease in insulation resistance. This result was found to be in contrast to the insulation resistance characteristics of the circuit breaker manufactured through the accelerated aging test. Therefore, the fire risk of aged circuit breakers was analyzed using the CTI.

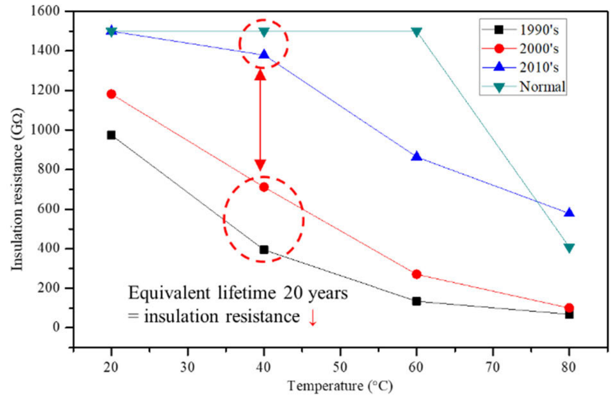



**FIGURE 6. Insulation resistance according to the degradation time of aged circuit breaker.**

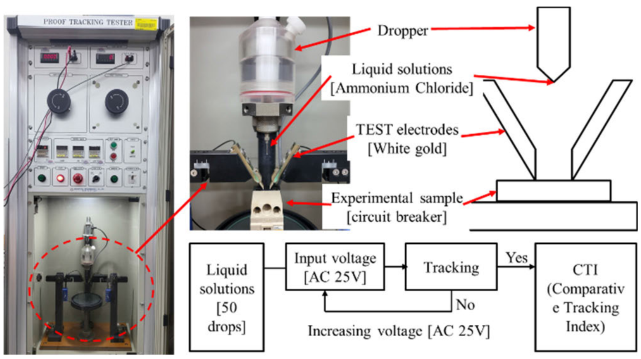



**FIGURE 7. Experimental setup of tracking test of circuit breaker.**

## IV. TRACKING INDEX OF LOW-VOLTAGE CIRCUIT BREAKERS ACCORDING TO THE DEGRADATION

### A. EXPERIMENTAL SETUP ACCORDING TO THE TRACKING TEST OF LOW-VOLTAGE CIRCUIT BREAKERS

IEC 60112:2020 specifies the test method for determining the proof and comparative tracking indices of solid insulating materials. Figure 7 illustrates the setup of the tracking experiment according to international standards. The tracking tester applies a liquid solution between the electrodes and monitors the formation of a carbonized conductive path based on the applied voltage. The electrode is white gold, and the liquid solution uses ammonium chloride. The comparative tracking index is the voltage at which tracking does not occur when 50 drops of liquid solution are dropped while increasing the applied voltage by 25 V, starting from AC 25 V.

Figure 8 shows the current between the electrodes when tracking occurs. The formation of a carbonized conductive path did not occur until approximately 30 drops of the liquid solution were applied. The current value changed as the liquid solution evaporated. After 30 drops, the current rapidly increased due to the formation of a carbonized conductive path, allowing for the detection of tracking. Therefore, the tracking risk resulting from the degradation was evaluated by comparing the tracking index of the circuit breaker manufactured through accelerated aging testing with that of aged circuit breakers collected from various locations in Korea.

### B. EXPERIMENTAL RESULT ACCORDING TO THE TRACKING TEST OF LOW-VOLTAGE CIRCUIT BREAKERS

In the case of a circuit breaker under normal conditions, no tracking occurred even at an input voltage of 400 V. This demonstrates insulation performance without the risk of fire due to tracking. However, the aged circuit breaker exhibited tracking at an input voltage of 125 V.

Figure 9 shows the distribution of aged circuit breakers according to the CTI. A total of 44 circuit breakers were

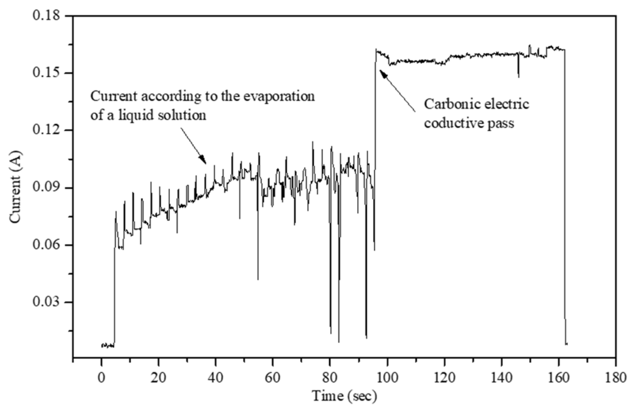



**FIGURE 8.** Current graph according to the formation of carbonized conductive pass.

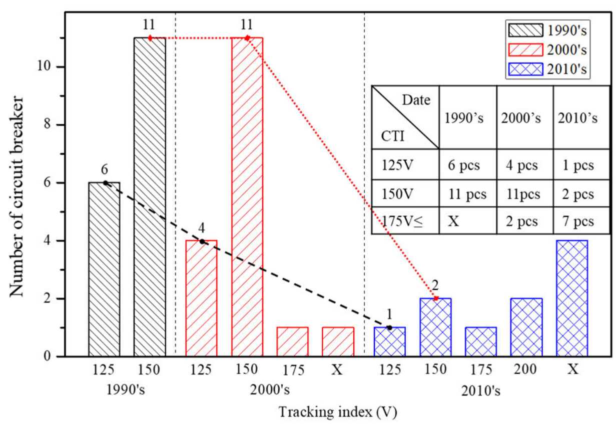



**FIGURE 9.** Number of aged circuit breakers according to the CTI.

used in the experiment, with 17 circuit breakers manufactured in the 1990s, 17 in the 2000s, and 10 in the 2010s. Among the circuit breakers manufactured in the 1990s, 6 had a CTI of 125 V, while 11 had a CTI of 150 V. Even in the 2000s, the CTI of most circuit breakers was measured between 125 and 150 V. However, there were cases in which circuit breakers experienced carbonized conduction or had a CTI of 175 V even at an input voltage of 400 V. In the case of circuit breakers manufactured in the 2010s, four did not exhibit carbonized conductive passes at an applied voltage of 400 V, representing the highest proportion among circuit breakers from the 2010s.

After conducting a tracking test on old circuit breakers collected from various parts of Korea, the CTI of aged circuit breakers decreased as the equivalent lifetime increased. However, the circuit breaker manufactured through the accelerated aging test did not exhibit the formation of a carbonized conductive pass despite the progression of degradation. Figure 10 depicts the aged circuit breaker and the tracking test process of the circuit breaker manufactured through accelerated degradation. The left photograph shows that a carbonized conductive path occurred at an applied voltage of 125 V

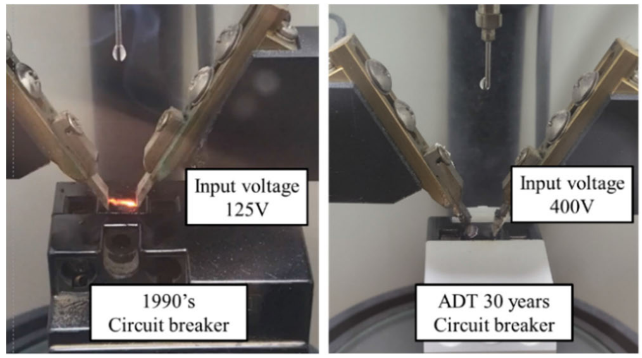


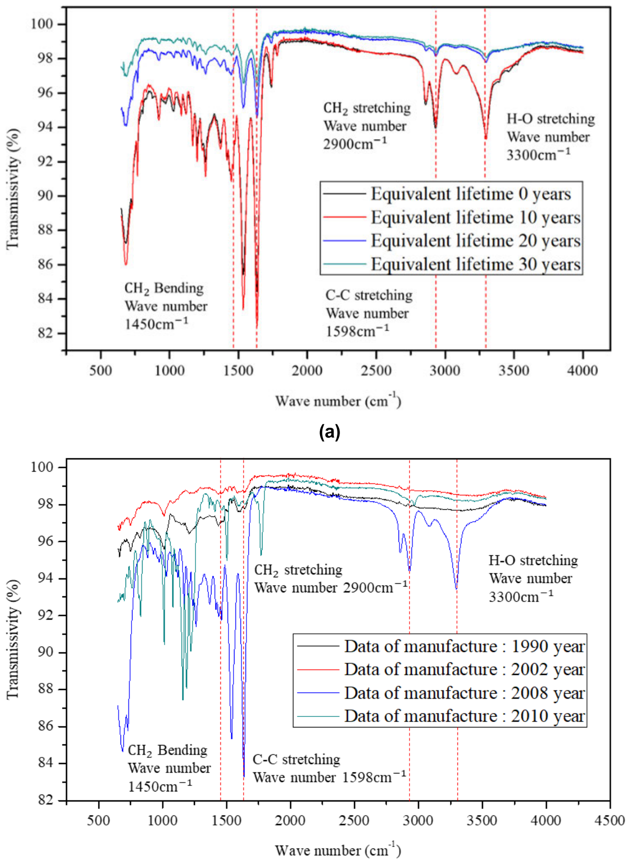

**FIGURE 10.** Photographs of the circuit breaker during the tracking test.

with an old circuit breaker. However, the right photograph shows that the carbonized conductive pass did not occur at the applied voltage of 400 V with the circuit breaker manufactured through the accelerated aging test. Therefore, the insulation performance of the low-voltage circuit breaker did not decrease due to the accelerated aging test under thermal stress and exhibited completely different insulation characteristics compared to the aged circuit breaker under actual field conditions. This result is attributed to the recrystallization phenomenon occurring when a certain level of heat is applied to the circuit breaker's insulator. Consequently, a component analysis test was conducted on the insulator of the circuit breaker manufactured through the accelerated aging test.

## V. TRACKING INDEX OF LOW-VOLTAGE CIRCUIT BREAKERS ACCORDING TO THE DEGRADATION

Fourier transform-infrared (FT-IR) spectroscopy is a technique used to obtain the infrared spectrum of the absorption or emission of a solid, liquid, or gas. When organic and inorganic compounds are exposed to radiation, they absorb energy in the infrared region, resulting in a unique spectrum for each substance. Therefore, we used spectral analysis to quantitatively and qualitatively analyze each component [25], [26].

Figure 11 shows the results of the FT-IR analysis according to the degradation time of the low-voltage circuit breaker. It represents the rate of IR penetration according to the frequency of the circuit breaker's insulator. This is speculated to be due to the removal of volatile substances that are added during the manufacturing of the polymer material. Specifically, the major bonding components of phenolic resin, indicated by dashed lines, such as H-O, showed an increase in transmittance from 93% at an equivalent age of 0 and 10 years to 98% at equivalent ages of 20 and 30 years. The C-C component also increased from 83% to 94%. However, it was observed that the major bonding components of phenolic resin only exhibited a decrease in transmittance while maintaining a consistent peak value. This implies that although a reduction in components occurred, the components themselves were not completely lost. Figure 11 (b) shows the experimental results of the




(b)

**FIGURE 11. Graph of the component analysis results for the aged circuit breaker. (a) Accelerated aging test (b) Aged.**

aged low-voltage circuit breakers. The transmittance of the circuit breaker manufactured in 1990 and 2002 was approximately 100%. In particular, no peak values were detected for the major bonding components of phenolic resin indicated by dashed lines. This indicates the decomposition of the polymer's bonding components. As thermal degradation progresses, it can impact the bonding structure of polymer materials. This is evident in the FT-IR spectra, where changes in the shapes of existing peaks are observed. Therefore, it is hypothesized that the aging of insulating materials can lead to the degradation of polymer bonding structures, consequently reducing their insulating performance. However, in the case of circuit breakers manufactured through accelerated testing, it is believed that exposure to high temperatures during the accelerated testing process triggers a recrystallization phenomenon, which helps in maintaining the bonding structure.

## VI. CONCLUSION

This study assessed the insulation characteristics of low-voltage circuit breakers through an accelerated aging test. The insulation resistance and CTI were measured to evaluate insulation performance. For circuit breakers manufactured using the accelerated aging test, insulation resistance increased compared to the circuit breakers under normal conditions. Additionally, the CTI remained unchanged as no carbonized conductive pass occurred during the accelerated aging test. To verify the reliability of the accelerated aging test, aged circuit breakers were collected from various locations in Korea, and their insulation resistance and CTIs were compared. The insulation resistance and CTI of the aged circuit breakers decreased as the equivalent lifetime increased. In particular, circuit breakers with an equivalent lifetime of 20 years or more showed a rapid decline in insulation resistance and a comparative tracking index, indicating a reduction in insulation performance due to degradation. Therefore, by analyzing the components of circuit breakers during degradation, it was observed that as degradation progressed, the circuit breaker components were lost, and in the case of aged circuit breakers, the insulator characteristics were compromised. It is hypothesized that as thermal decomposition progresses, it can lead to the breakdown of the polymer's bonding structure, ultimately resulting in a decrease in insulation performance. However, circuit breakers manufactured through accelerated testing are exposed to high temperatures, which, in turn, induce the phenomenon of polymer recrystallization. This is believed to occur as the polymer's bonding structure reforms, thereby maintaining insulation performance. Based on the aforementioned findings, it can be concluded that the application of an accelerated aging test involving thermal stress is not viable for low-voltage circuit breakers. Hence, it is imperative to establish accelerated aging test conditions that encompass additional degradation factors, apart from thermal degradation.

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