Proposal of Circuit Breaker Type Disconnector for Surge Protective Device

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Abstract: - A disconnector for an SPD (Surge Protective Device) is equipment that disconnects a circuit when the SPD fail in a short circuit mode. The disconnector and the SPD are connected in series. A fuse or a circuit breaker is normally used as a disconnector. However there are problems with both methods. A fuse is not recyclable once it goes out. Even a circuit breaker is resettable, a lightning surge current causes a switchgear of circuit breaker to open unnecessarily. This malfunction spoils the overvoltage protective function of the SPD which eliminates a lightning surge current into an electrical apparatus. If the problem which a switchgear of circuit breaker to open unnecessary can be solved, an electrical apparatus can be protected by the SPD. This paper presents several approaches preventing circuit breaker type disconnectors from the malfunction.

Key-Words : circuit breaker, disconnector, surge protective device, short circuit mode , lightning surge

1 Introduction
This paper proposes a disconnector that conducts a current generated by lightning and that blocks a current from a commercial power supply. A disconnector for an SPD is equipment that disconnects a circuit when the SPD may fail in a short circuit mode. The disconnector and the SPD are connected in series. A fuse or a circuit breaker is normally used as a disconnector. However there are problems with both methods. A fuse is not recyclable once it goes out. Even a circuit breaker is resettable, a lightning surge current causes a switchgear of circuit breaker to open unnecessary. Because electrical control circuits of conventional circuit breakers can not distinguish between a lightning surge current from an alternative overcurrent. Another reason is a switchgear of the conventional circuit breakers to open unnecessary according to the electromagnetic force generated by a lightning surge current.

This malfunction caused by a lightning surge current spoils the overvoltage protective function of the SPD which eliminates a lightning surge current into an electrical apparatus. If the problem which a switchgear of circuit breakers to open unnecessary can be solved, even when lightning surge current flows through it, an electrical apparatus can be protected by the SPD. We propose several approaches preventing the switchgear malfunction using electrical control circuit to be able to distinguish between a lightning surge current from an alternative overcurrent as well as using loop forming switchgear structure.

2. Problems on Disconnector
Fig. 1 is a configuration example of an overvoltage protective device combining disconnectors and SPDs. A disconnector needs to be connected in series to an SPD and be installed between an electric wire and an earth. Therefore the disconnector should conduct a current generated by lightning and block a current from a commercial power supply. However a lightning surge current causes a switchgear of circuit breaker to open unnecessary.

![Diagram of Overvoltage Protective Device](image-url)
3. Improvements on Electrical Control Circuits

An object of the new approaches is to provide a disconnector that satisfies flowing a lightning surge current, blocking a current from a commercial power supply both in cases of earth fault and interphase short circuit. Because conventional circuit breakers can not distinguish between a lightning surge current from an alternative overcurrent.

3.1 First Idea

Fig. 2 is a diagram showing a specific configuration example of the disconnector 200.

The current vector sum detecting part 150 is constituted by a diode 151 and resistors 152, 153, and 154. The bypass part 160 is constituted by a transistor 161 and a resistor 162.

Fig. 2 Specific configuration example of the disconnector 200.

There is no or little output voltage from the ZCT 151 when there is no lightning surge current, so the output voltage from the current vector sum detecting part 150 is low. Therefore, the transistor 161 is OFF, and the current does not flow through the bypass part 160. Thus, the output current from the rectifying part 110 generated by the follow current is stored in the charging part 120. When the lightning surge current flows, the output voltage of the current vector sum detecting part 150 becomes higher than the operating voltage of the transistor 161. The transistor 161 then turns on, and the current flows through the bypass part 160. Therefore, the output current from the rectifying part 110 generated by the lightning surge current is hardly stored in the charging part 120. Thus, in the present approach the value of Q (charge that can be stored in the charging part by the lightning surge current) is very small. The follow current can be blocked because the disconnector 200 can set the capacitance value of the capacitor 121 to the minimum capacitance that the trip coil 141 operates the switchgear 142. Since the bypass part 160 of the disconnector 200 does not store the output current from the CTs 101, 102, and 103 generated by the lightning surge current in the charging part 120, there is no fear that the lightning surge current operates the switchgear 142.

For example, a coil having a silicon steel sheet core 30 mm in dimension and having 6000 turns is used for the ZCT. A coil having a silicon steel sheet core 20 mm in dimension and having 3000 turns is used for the CT. The capacitance value of the capacitor 121 is set to 17 μF, the capacitance value of the capacitor 131 is set to 0.47 μF, the resistance value of the resistor 132 is set to 4.7 kΩ, the resistance value of the resistor 133 is set to 2.2 kΩ, and the resistance value of the resistor 162 is set to 6 kΩ. Such a disconnector 200 does not operate under the lightning surge current of 50 kA and can block a 2 A (50Hz) or higher follow current. Short circuit breaking of about 10 kA (50Hz) is also possible.

3.2 Second Idea

Fig. 3 shows a specific configuration example of the disconnector 300. The delay part 170 is constituted by a capacitor 171, a resistor 172, a thyristor 173, a current limiting circuit 174, and diodes 175 and 176.

When the lightning surge is not generated, there is no output current from the rectifying part 110, and the charge of the capacitor 171 is 0. Therefore, the thyristor 173 is OFF, and the current from the rectifying part 110 does not flow through the charging part 120. When the lightning surge is generated, the current from the rectifying part 110 is charged to the capacitor 171 through the current limiting circuit 174. When the voltage of the capacitor 171 exceeds a predetermined value, the thyristor 173 is turned on. The time from the generation of the lightning surge current to the turning on of the thyristor 173 is a delay generated by the delay part 170. If the current value of the current limiting circuit 174 and the capacitance value of the capacitor 171 are designed so that the delay time is several 100 μ seconds, the current from the rectifying part 110 by the lightning surge current is not charged to the charging part 120. The resistor 172 is arranged to discharge the charge of the capacitor 171 to return the thyristor 173 to the initial OFF state when there is no more lightning surge current. The diodes 175 and 176 are arranged to prevent the backflow.

When the thyristor 173 is turned on, the current from the rectifying part 110 is also charged to the capacitor 121 of the charging part 120. However, the current is not charged to the capacitor 121 if there is no follow current. Therefore, the switching part 140 is not driven. On the other hand, the charge is stored in the capacitor 121 if there is a follow
current. When the charge stored in the capacitor 121 exceeds a predetermined value, the trigger part 130 drives the switching part 140, and the electric wires are disconnected. In the present approach, the value of Q (charge that can be stored in the charging part by the lighting surge current) is very small. Therefore, the capacitance C of the capacitor 121 can also be made small.

The size of the various materials used in the model of Fig. 4 is listed in Table 1. Moreover, whenever the disconnector operates repeatedly, the contact surface of the silver 2 of a contact part will be roundish.

To estimate this effect, the contact surface of a switchgear having one point contact as shown in Fig. 5 was modeled.

<table>
<thead>
<tr>
<th>Material</th>
<th>Y-axis breadth [mm]</th>
<th>X-axis length [mm]</th>
<th>Z-axis thickness [mm]</th>
<th>Radius [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brass</td>
<td>8.0</td>
<td>16.0</td>
<td>1.0</td>
<td>-</td>
</tr>
<tr>
<td>Silver1</td>
<td>-</td>
<td>-</td>
<td>2.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Silver2</td>
<td>4.0</td>
<td>6.2</td>
<td>1.0</td>
<td>-</td>
</tr>
<tr>
<td>Copper</td>
<td>3.0</td>
<td>23.0</td>
<td>6.0</td>
<td>-</td>
</tr>
</tbody>
</table>

Fig. 3 Specific configuration of the disconnector 300.

Fig. 4 Conventional circuit breaker model (Flat contact model)

4 Improvement of Switchgear

4.1 Problems on Conventional Switchgear

In conventional circuit breaker, when a lightning surge current flows, large electromagnetic force works in the switchgear. In order to investigate the characteristics of the electromagnetic force in each conductor when the lightning surge current flows, as shown in Fig. 4, the electrode form of circuit breaker was modeled.

Table 1. Size of conventional model

Fig. 5 Conventional circuit breaker model (One point contact model)

(a) 3D model

(b) Cross section

Fig. 5 Conventional circuit breaker model (One point contact model)

(1) Current density analysis

The analyzed results of current density, when both a 50Hz AC current and a lightning surge current flow into the conventional circuit breaker model, are shown in Fig. 6. When the current density of each conductor of the conventional circuit breaker model was seen, in the case of lightning surge current, compared with AC overcurrent, the
The frequency component was high and it became clear that the influence of a skin effect appears strongly.

(a) AC 50 kA (50Hz)

(b) Lightning Surge 50 kA

Fig. 6 Current density analyzed results (Conventional circuit breaker model)

Therefore, since the lightning surge current makes it difficult to pass through in the central part of each conductor and much current is flowing through the surface of a conductor. From this, it is expected that the power generated by lightning surge current is stronger than that of AC overcurrent.

Fig. 7 Current vector (Conventional circuit breaker one point contact model)

The vector of the current density when lightning surge current flows into a conventional circuit model is shown in Fig. 7.

The result of Fig. 7 shows that current is concentrating at one point contact surface.

When the vector ingredient of current is decomposed as shown in Fig. 8(a), current flows in and flows out of one point contact point. As horizontal components of the current vectors are opposite directions, an electromagnetic force works to separate each other as shown in Fig. 8(b) which means to make the switchger open unnecessary.

(a) Decomposition of current vectors

(b) Power committed on parallel current

Fig. 8. Electromagnetic force to make the switchger open unnecessary

(2) Electromagnetic force analyzed results

The electromagnetic force analyzed result in the direction of the Z-axis committed to the conventional circuit breaker model when lightning surge current flows is shown in Fig. 9. Here, the Z-axis shows the top and bottom direction of the model.

When the direction of power which works each material was seen from the result of Fig.9, the below power worked to brass and silver 1, the above power worked to silver 2 and copper. And it became clear that the power working...
between conductors (brass, copper) is bigger than the power working a contact part (silver 1, silver 2).

As these analyzed results, it was proved that big power in the direction of the Z-axis of a switchgear make a contact point comes open.

Therefore switchgear problem to open unnecessary based on the electromagnetic force in the direction of the Z-axis must be solved.

### 4.2 Improvement of Switchgear using Loop Form Model

As shown in Fig.10 we considered the model which improved brass forming loop. By making brass into loop form, the current of the same direction flows between brass (top) and copper. Although electromagnetic force works to separate brass (bottom) from copper simultaneously, electromagnetic force works to close together stronger because the distance of brass (top) and copper is nearer. Therefore, it is thought that switchgear to open unnecessary can be solved.

The electromagnetic force analyzed result of the direction of the Z-axis committed to a loop form model when lightning surge current flows is shown in Fig.11. As the electromagnetic force to close together which works between conductors (brass, copper) is stronger than the electromagnetic force to separate which works in a contact part (silver 1, silver 2).

Therefore, the electromagnetic force to close together works between terminals if lightning surge current flows.

In the case of lightning surge current, since strong power is working compared with AC50kA (50Hz), it is expected that the point of contact of a switchgear does not intercept. It became clear that loop form model is much better than a conventional circuit breaker model.

### 5. Experimental Test Results

In order to clarify the validity of the proposed methods, we tested them as shown in Fig. 12. Fig.13 shows one example of lightning surge waveform (class I, 10/350μs) applicable for direct lighting surge currents. Based on the new approaches, a disconnector was developed for an experiment.

Table 2 lists the test results on operation performance of the models under the condition of lightning surge current. The switchgear of several conventional circuit breakers could endure up to only 10~15kA (10/350μs). On the other hand, the disconnector using new approaches could endure up to 40kA (10/350μs). We found that proposed model obtained good test results.
Table 2 Test Results

<table>
<thead>
<tr>
<th>Disconnector</th>
<th>Experimental results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional circuit breakers</td>
<td>10–15kA (10/350μs)</td>
</tr>
<tr>
<td>Proposed circuit breaker</td>
<td>40kA (10/350μs)</td>
</tr>
</tbody>
</table>

6. Product Specifications

This disconnector is available on the market. The photograph of the product is shown in Fig. 14. And main specifications of the product are listed in Table 3.

The disconnector mentioned above is not affected by the voltage variation of the commercial power supply due to the lightning surge superposition or the like because the disconnector is not supplied with an electrical power from a commercial power line. Also the voltage drop in the case of the lightning surge current is negligible because of using only current transformers without using electrical relay.

Table 3 Main Specifications

<p>| | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>AC100V, 200V 50/60Hz</td>
</tr>
<tr>
<td>Applicable SPD Class</td>
<td>Class 1 SPD <strong>40kA</strong></td>
</tr>
<tr>
<td>Earth fault detection</td>
<td>2.5A or higher</td>
</tr>
<tr>
<td>Short circuit current</td>
<td>7.5 kA</td>
</tr>
</tbody>
</table>

7. Conclusions

This paper proposed a disconnector that conducts a current generated by lightning and that blocks a current from a commercial power supply.

1. The disconnector using new approaches could endure up to 40kA (10/350μs) in experiments.

2. The 50Hz current of the commercial power supply can be blocked both in cases of earth fault (2.5A or higher follow current) and interphase short circuit (7.5 kA).

3. The disconnector is not affected by the voltage variation of the commercial power supply due to the lightning surge superposition or the like because the disconnector is not supplied with an electrical power from a commercial power line.

References

[6] H. Kijima, Overvoltage protective device and method, EU patent application has been approved, 2013