Abstract: - Overvoltage protective devices are used for protecting apparatuses against overvoltage or overcurrent caused by lightning surge. Overvoltage protective components are mainly divided into two categories. One is clamping type and the other is switching type. Typical clamping type overvoltage protective components are varistors and diodes. Typical switching type overvoltage protective components are gas-filled discharge tubes and air gaps. Both clamping type and switching type overvoltage protective components have problems when using them alone. This paper proposes a new technology consisting of both clamping type and switching type overvoltage protective components in order to solve the problems of them. It is that three or more switching type components are connected in series and two or more clamping type overvoltage protective components are connected in parallel. Problems of both of them can simultaneously be solved by reducing the maximum voltage with high response time and high current capability, and so on.

Key-Words: overvoltage protective device, varistor, diodes, discharge tube, air gap

1 Introduction
This paper presents a new technology for protecting apparatuses against overvoltage or overcurrent caused by lightning surge.

Both the characteristics of lightning surge and overvoltage protection technologies have been introduced in the articles [1][4]. Fig. 1 shows the profile S(t) of voltage or current caused by lightning surge. Generally, a direct lightning strike causes a current having a peak value of several tens of kA to flow, and an induced lightning surge causes a voltage having a peak value of several 10 kV. And also for example, a front time is several μsec and a mean time to half value is several 100 μsec.

Typical clamping type overvoltage protective components are varistors and diodes. Typical switching type overvoltage protective components are gas-filled discharge tubes and air gaps. Both of them have problems when using them alone.

This paper proposes a new technology consisting of both clamping type and switching type overvoltage protective components. It is that three or more switching type components are connected in series and two or more clamping type overvoltage protective components are connected in parallel. Problems of both of them can simultaneously be solved by reducing the maximum voltage with high response time and high current capability, and so on.

2 Problems in the case of using varistor alone

Fig. 2A shows a configuration for overvoltage protection in the case of using a varistor. Even when an overvoltage is applied across terminals 902 and 903, an overvoltage is not applied across terminals 904 and 905 by virtue of a varistor 901. Fig. 2B shows an ideal change of voltage across indoor side terminals when a varistor is used.
3 Problems in the case of using GDT alone

Fig. 3A shows a configuration for overvoltage protection using a Gas-filled Discharge Tube (GDT).

![Fig. 3A](image)

Fig. 3A A configuration for overvoltage protection using a GDT

Fig. 3B shows an ideal change of voltage across indoor side terminals. In the case of using a GDT, when an overvoltage applied from the outdoor side exceeds operating voltage B, the voltage across the GDT terminals becomes sharply low by discharge. After the discharge starts, the voltage across the GDT terminals is lowered to arcing voltage A for example 50 V. However, when a commercial power supply of, for example, 100 V is used, if arcing voltage A is lower than 100 V, even after the overvoltage caused by a lightning surge disappear, discharge will continue due to the current supply from power line. Accordingly countermeasures are taken such as connecting other GDTs in series to raise total arcing voltage to more than 100 V.

Such extinguishing of discharge once generated by the lightning surge and continued by the commercial power supply is referred to as “follow current interrupt”.

If to increase the number of GDTs in series, the response time become slow because total voltage is divided by the number of GDTs. And also, operating...
voltage becomes high.

Fig. 3C shows the change of current flowing through a GDT. In the case of a GDT, when voltage across the GDT is high (until discharge occurs), current does not flow through the GDT; when current starts to flow, the voltage lowers for example 50 V due to low impedance value caused by arcing. Consequently, instantaneous power (voltage\times current) as well as energy (time integration of instantaneous power) is relatively small. Accordingly, in the case of a GDT, even when an extremely large current for example 50 kA flows, its life is not so affected.

Varistors and diodes being used as a clamping type overvoltage protective component are typically composed of a semiconductor. Accordingly, time $T_C$ as dealt with in Figs. 2B and 2C taken for a clamping type overvoltage protective component to reach its operating voltage is as small as 0.01 $\mu$s. On the other hand, a GDT is based on a discharge phenomenon, so time $T_D$ as dealt with in Figs. 3B and 3C taken to reach its operating voltage is 0.1~1 $\mu$s, which is relatively long.

4 Problem Solution using combination of three GDTs and two varistors

Fig. 4 shows a configuration of an overvoltage protective device. In Fig. 4, three GDTs 101, 102 and 103 in series and two varistors 104 and 105 in parallel are used.\[6]-[9]

Here, the operating voltage of the GDT 102 is set lower than a voltage obtained by subtracting the arcing voltage of the GDT 103 from the operating voltage of the varistor 104, and lower than a voltage obtained by subtracting the arcing voltage of the GDT 101 from the operating voltage of the varistor 105, and at the same time higher than the operating voltage of the GDT 101 and the operating voltage of the GDT 103. The varistors 104 and 105 each need not to be consisting of only one varistor, and several varistors connected in series or parallel may be used as the varistors 104 and 105.

Figs. 5 to 9 show the operations when overvoltage $S(t)$ is applied across outdoor side terminals 111 and 112. Even when overvoltage $S(t)$ is applied across outdoor side terminals 111 and 112, none of the GDTs 101, 102 and 103 discharges in the first state. At this time, current does not flow through the varistors 104 and 105. Accordingly, no potential difference is generated between both ends of the varistors 104 and 105. Consequently, voltage $S(t)$ is applied to each GDT.

This state is shown in Fig. 5. When the varistors 104 and 105 are not provided (i.e., when the GDTs alone are connected in series), approximately one-third the voltage of $S(t)$ is applied to each GDT. More specifically, the varistors 104 and 105 serve to raise the voltage applied to each GDT, thereby enabling a high response time. Consequently, each GDT has potential difference as shown in Fig. 6.

The operating voltage of the GDT 102 is set higher than that of the GDTs 101 and 103. Accordingly, the
GDT 101 or the GDT 103 first discharges. For example, assume that the GDT 103 discharges. At this time, the arcing voltage of the GDT 103 becomes $A_3$. Also, current flows through the varistor 105, so operating voltage $C_5$ of the varistor 105 is generated. Thus the voltage across indoor side terminals 113 and 114 becomes $C_5 + A_3$. Current does not flow through the varistor 104, so no potential difference is generated between the terminals of the varistor 104.

The operating voltage of the GDT 101 is lower than that of the varistor 105, so the GDT 101 discharges. Once GDT 101 discharges, current flows through the varistor 104, and operating voltage $C_4$ is generated. At this time, the voltage across indoor side terminals 113 and 114 is equal to the lower one of $C_4 + A_1$ and $C_5 + A_3$. It may be designed so that $C_4 + A_1 = C_5 + A_3$. At this time, each unit has potential difference as shown in Fig. 7.

The operating voltage of the GDT 102 is lower than voltage $C_4 - A_3$ obtained by subtracting arcing voltage $A_3$ of the GDT 103 from operating voltage $C_4$ of the varistor 104, and lower than voltage $C_5 - A_1$ obtained by subtracting arcing voltage $A_1$ of the GDT 101 from operating voltage $C_5$ of the varistor 105. Thus the GDT 102 also discharges. Potential differences of each GDT in this state are shown in Fig. 8. In such state, almost the entire overcurrent can be made to flow through the GDTs. When the overall arcing voltage $A_1 + A_2 + A_3$ is set higher than the commercial power source (150 V, for example), the problems of both follow current interrupt and short circuit current capability can be solved. Also, in this configuration, coils and resistors for energy coordination are not installed between terminals 111 and 113, so it is possible to reduce the size and cost, and a problem of the unbalance between conductor 115 and conductor 116 does not arise.

Practically, the operations of Figs. 5 to 8 are performed in several μsec. Thus the voltage across indoor side terminals 113 and 114 varies as shown in Fig. 9A. Reference character B in Fig. 9A indicates an operating voltage when the GDTs 101, 102 and 103 alone are connected in series (i.e., when the varistors 104 and 105 are not provided). As the varistors 104 and 105 work as a trigger for GDT’s discharges mentioned above, the operating voltage can be lowered to B’. Consequently, a high response time is possible and the maximum voltage can be lowered.
Fig. 9B shows the change of current flowing between the conductors 115 and 116. In this configuration, with voltage lowered, almost the entire current can be made to flow through the GDTs 101, 102 and 103, so a problem of life of varistor due to instantaneous power and energy does not arise. Therefore high lightning surge current capability can be achieved.

When an overvoltage having negative polarity \( S(t) \) relative to outdoor side terminal 112 is applied to the terminal 111, one having a lower operating voltage from among the GDTs 101 and 103 is activated. If the GDTs 101 and 103 are designed to have the same operating voltage, symmetry can be improved. If the GDTs 101 and 103 are designed so that either of them has a lower operating voltage, a GDT which first discharges can be selected. When the GDT which first discharges is selected, the improvement in symmetry of the overvoltage protective device cannot be expected without improving symmetry of positive and negative polarities relative to lightning surge of the GDT itself. The degree of symmetry needed differs depending on application, and thus it may be designed considering the characteristics and application of components used.

5 Problem Solutions using other variations of overvoltage protective components

Variations according to the above idea will be described below\(^{[6] - [9]}\).

Fig. 10 shows an example in which four electrodes 1061 to 1064 are arranged within one GDT to provide three discharge units. The operation of the present variation is the same as that of mentioned in chapter 4. An air gap is also available instead of a GDT. A diode is also available instead of a varistor. As a diode has polarity, two diodes should be used as a pair.

Fig. 11 shows a variation which connects five GDTs in series and four varistors in parallel. Here, assume that the operating voltage of the GDT \( n (n = 141 \text{ to } 145) \) is \( B_n \), the arcing voltage is \( A_n \), and the operating voltage of the varistor \( m (m = 156 \text{ to } 159) \) is \( C_m \).

The operating voltage \( B_{143} \) of the GDT 143 is set so as to satisfy the following conditions.

\[
\begin{align*}
B_{143} &< C_{156} - A_{142} - A_{144} - A_{145} \\
B_{143} &< C_{157} - A_{144} - A_{145} \\
B_{143} &< C_{158} - A_{141} - A_{142} \\
B_{143} &< C_{159} - A_{141} - A_{142} - A_{144}
\end{align*}
\]
When the above setting is given, while overvoltage is concentrated to GDTs to be activated, discharge can be sequentially started. In order to improve the symmetry of the entire overvoltage protective device, the following setting is required: $B_{141} = B_{145}$, $B_{142} = B_{144}$, $C_{156} = C_{159}$, and $C_{157} = C_{158}$. Further, in order to activate the GDTs unfailingly in order of being closer to the conductor, the following setting is required: $B_{141} < B_{144}$ and $B_{145} < B_{142}$. Herein, “activate the GDTs unfailingly in order of being closer to the conductor” means that the GDTs 141 and 145 are first activated, and thereafter the GDTs 142 and 144 are activated, and finally the GDT 143 is activated.

We can increase the number of GDT $n$ ($n \geq 7$) and the number of varistor $m$ ($m \geq 6$) using the same procedure mentioned above. We can set the overall arcing voltage $A_1 + A_2 + A_3 + \cdots + A_n$ higher than that of commercial power supply, the problems of both follow current interrupt and short circuit current capability can be solved.

### 6 Conclusion

This paper proposed a new technology on overvoltage and overcurrent protection, consisting of both clamping type and switching type overvoltage protective components. The advantages of this new technology in the case of using GDTs as switching type overvoltage protective components and varistors as clamping type overvoltage protective components are as follows.

I. When there is no overvoltage or overcurrent,

1. No leakage current, because one GDT is always connected to a varistor in series.
2. No affection on Power Line Communication, because one GDT is always connected to a varistor in series.

II. When there are overvoltage and overcurrent,

3. No dependence on lightning surge polarities, due to symmetric configuration
4. Low operating voltage with high response time, because varistors serve to raise the voltage applied to each GDT.
5. High lightning surge current capability, because almost the entire current flow through the GDTs, a problem of life of varistors due to heating does not arise.
6. Both follow current interrupt and short circuit current capability can be solved, because we can set the overall arcing voltage higher than that of commercial power supply by increasing the number of GDTs in series.

### III General

7. Coils and resistors are not necessary, thus minimizing the size and cost.
8. No disadvantages.

### References:

[9] H. Kijima, Overvoltage protective device and method of overvoltage protection, to be filed in China, India, USA and EU.