# Discharge Phenomena of the Insulator Assembly and Occurrence of Critical Cascading Flashover Phenomena

By

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**Abstract**

This paper describes conditions for an occurrence of cascading flashover phenomena on the insulator assembly with the use of a high voltage transmission line by experiments in a laboratory room. The 154 kV suspension insulator assembly is employed as testing apparatus which consists of a chain of 9 standard suspension insulators equipped with an arcing horn. In the experiments, the apparatus is separated into two parts consisting of a bare insulator chain and a pair of arcing horns. The lightning impulse with positive polarity or negative are applied to the test pieces, and the over-voltage is used in those tests. Thus, the creeping flashover occurred with short lag time. The V−t curves and the 50% cascading flashover voltage were obtained and the pre-breakdown phenomena were observed from the tests, then, it is concluded that the critical cascading flashovers occur with short time lag ($T_o$=1.8 $\mu$ sec. or less) and a high steepness (1833 kV/$\mu$ sec. or more), and corona on the insulator surface starts from negative side electrode.

## 1. Introduction

As regards saving energy, one of the most important matters is the efficient utilization of electric energy. In Japan, the power sources are located far from the consumers, and in order to decrease transmission losses, the electric energy must be sent through high voltage transmission lines. Howerer, the transmission lines must pass over mountain areas by reason of the geography of the land in Japan. In such areas, they are struck frequently by lightning in winter as well as in summer.[1]

When the ground wire or tower is struck by the lightning, the potential of the tower increases due to the lightning current, depending on the earth resistance and

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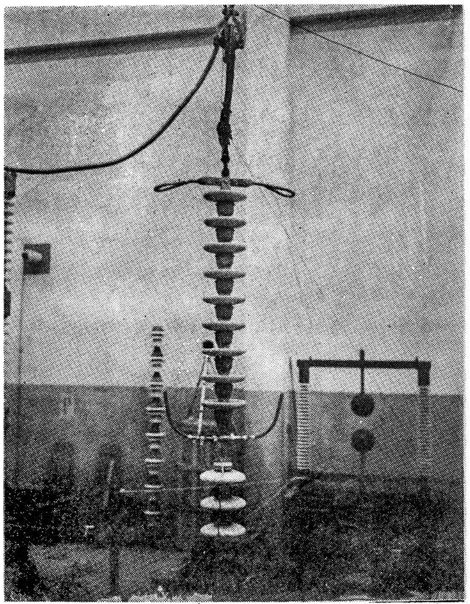


Fig. 1. The Testing Suspension Insulator Assembly for Transmssion Line (It is reversed hanging)

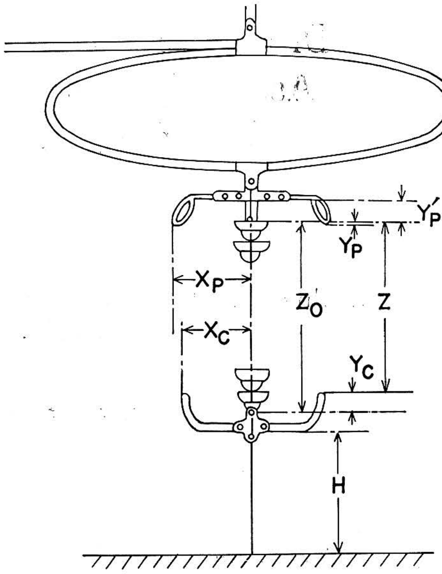
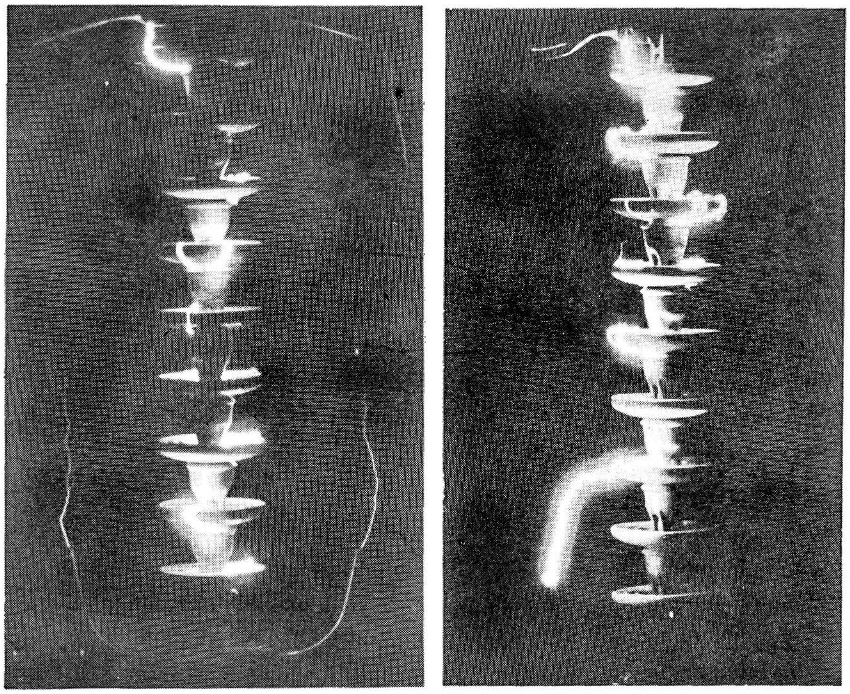



Fig. 2. The Testing Insulator Assembly and the Horn Arrangement

the surge impedance of the tower, as well known. Such a potential rise often leads to a fiashover of the insulator assembly. This is referred to as the reversible breakdown.

An insulator assembly equipped with the 250 mm suspension insulators, the arcing horn and the suspending metal fittings which are used for high voltage transmission lines are shown in Figs. 1 and 2. The number of the suspension insulators is calculated from an estimated maximum density of salt deposit on the surface of the porcelain, and from the class of the transmission voltage.[2]

The purpose of the arcing horn is to protect the porcelain from the heat destruction due to the lightning current and following currents of the A.C.. The gap length of the arcing horn is adjusted to allow a fiashover by a lower voltage than the breakdown voltage of the insulator chain without the horn. When a fiashover occurs at the insulator assembly equipped to the transmission line, due to the lightning surge of a very high over-voltage, the phenomenon occasionally changes to a creeping discharge in spite of the presence of the arcing horn, as shown in Fig. 3. These phenomena are referred to as critical cascading fiashovers. We have performed experiments concerning these phenomena on insulator assemblies in a laboratory room, and the conditions of critical cascading fiashovers. Some of these experimental results have been published in previous reports already.[3),4)]



(a) (b)

Fig. 3. The Creepage Flashover Phenomena
(a) Positive Applied Voltage
(b) Negative Applied Voltage

## 2. Experimental Methods and Conditions

For our experiments, the 154 kV suspension insulator assembly is employed as the test apparatus, which is shown in Figs. 1 and 2.

This insulator assembly consists of a chain of 9 standard suspension insulators equipped with an arcing horn. The dimensions of the arcing horn are shown in Fig. 2 and Table 1. In this breakdown test, the insulator assembly is hung in an opposite direction from the ordinary setting by reason of the limited height of the ceiling and the arrangement of the measuring instruments. Also this insulator assembly is located far from other various conductive substances and the floor which distort the electric

Table 1 The Horn Dimension of the 154 kV Suspension Insulator Assembly Having 9 Standard Insulators (mm)

| Horn Dimension | $X_c$ | $X_p$ | $Y_c$ | $Y_p$ | $z$ | $z_c$ |
|---|---|---|---|---|---|---|
| The Testing Assembly | 400 | 450 | 200 | 0 | 1130 | 1330 |
| A Utility Assembly | 385 | 430 | 202 | 0 | 1130 | 1332 |

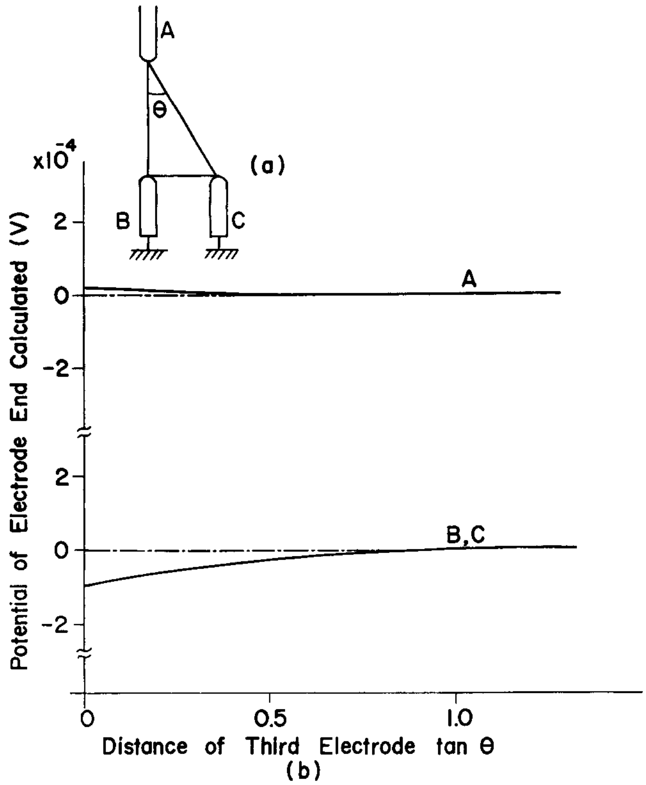



Fig. 4. Potential Correctness of Each Electrodes When Exist Nearby the Third Electrode

field. These separated distances are the twice or more the gap length, as determined by the calculation of the electric field that is investigated in the case of the rod-rod electrodes with the nearby third electrode shown in Fig. 4 (a). From the calculation, the electric field in the gap, in such a case, is distorted to a certain percent, due to the surroundings as shown in Fig. 4 (b).

The depth ($Y_p$: table 1) of the overlapping arcing horn (2 cm $\Phi$ metal rod) on the side of the voltage application is zero, and the shape of the horn end is of hoop-shape in order to weaken the electric field around the test apparatus. The corona discharge on the horn end can be not found for a lower voltage. On the other side, the depth ($Y_c$) of the overlapping arcing horn (2 cm $\Phi$ metal rod) on the earth side is of 20 centimeters. This arrangement of the insulator assembly is standard for the 154 kV transmission line at the normal district in metheologic conditions.[4)]

The electrical circuit and meauring instruments are shown in Fig. 5. The wave form of applied voltage is $\pm(0.6\times40\ \mu$ sec.). The circuit contains chopping gap

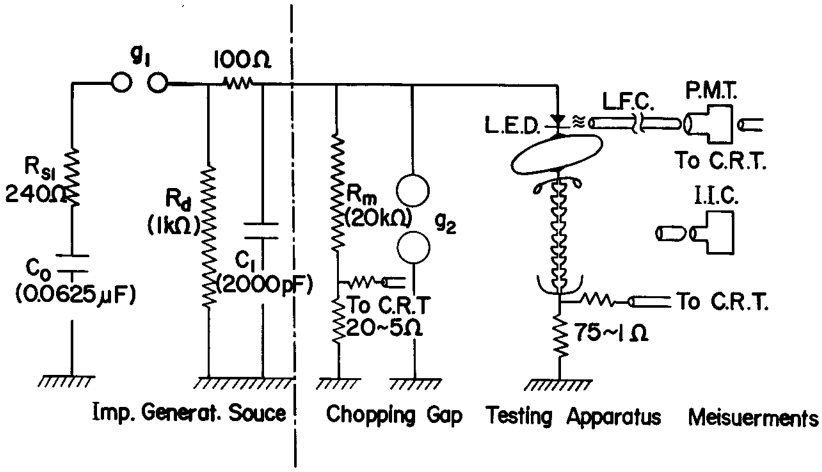



Fig. 5. The Circuit in Use of the Experiment

consisting of a pair of spheres. By the adjusting gap length, the chopping time can be varied, and the pre-breakdown corona at each stage can be observed by means of a camera with an image intensifler tube combined with a chopped wave voltage. Against the following three types of testing apparatus consisting of an arcing horn pair and a chain of the standard suspension insulators, a fifty percent breakdown voltage by the up-down method and the voltage–time ($V-t$) curve were obtained for the impulse voltage. The types of electrodes tested here are as follows;

1) normal "insulator assembly"
2) bare "insulator chain" without arcing horn
3) "a pair of arcing horns" without insulator chain

The experiments for each $V-t$ curve have been performed refering to JEC 171.[5)]

## 3. Experimental Results

The results of a breakdown test on a normal insulator assembly of 9 standard suspension insulators with the arcing horn are shown in Table 2 and Figs. 6 and 7 against positive and negative impulse voltages respectively. In those figures, it is deduced that if the breakdown voltage was of 1100 kV or more and the breakdown time ($T_o$) less than 1.8 $\mu$ sec., a critical cascading fiashover occurs. The rise time rate of applied voltage in such a case is 1833 kV/$\mu$ sec.. The additional experiments were executed as follows.

Table 2. The Fifty Percent Breakdown Voltages for Three Type Testing Apparatus

| | Polarity | Insulator Assembly | Insulator Chain | Horn Pair |
|---|---|---|---|---|
| $V_{50}$ | P. | 720kV | 873kV | 754kV |
| | N. | 708kV | 950kV | 741kV |

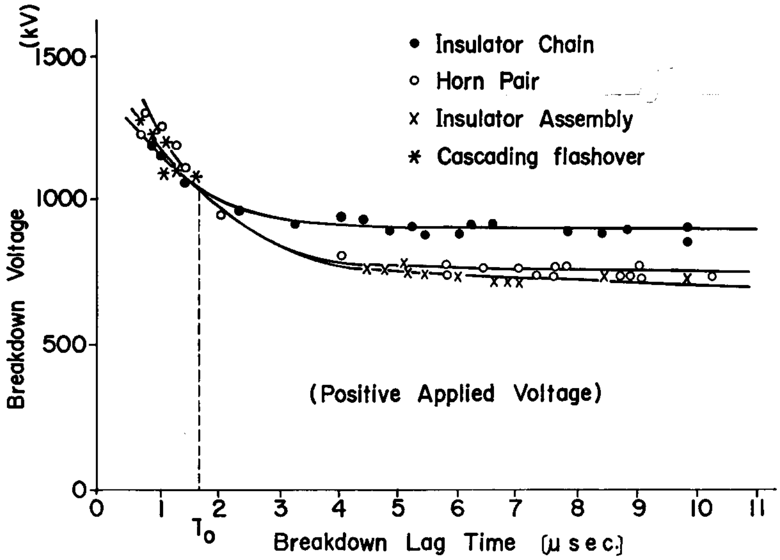
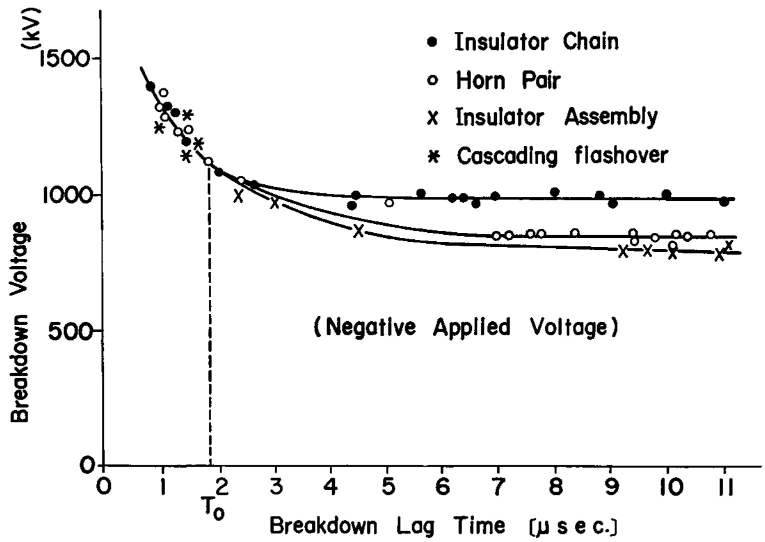



Fig. 6. $V-t$ Characteristics of Various Conditions of Insulator Assembly




Fig, 7, $V-t$ Characteristics of Various Conditions of Insulator Assembly

Against the testing apparatus of types 1), 2), and 3) as described above. a flfty percent breakdown voltage ($V_{50}$) and $V-t$ curves were obtained and also a growing pre-breakdown corona was observed in such cases.

In the case of type 2), $V_{50}$ is shown on Table 2, and $V_{50}$ for type 2) electrode is maximm. $V_{50}$ for types 1) and 3) are almost equal because the breakdown occurs in the gap of the arcing horn. The $V-t$ curves for the three types of test instruments are shown in Fig. 6 for the positive polarity and in Fig. 7 for the negative respectively.

In both figures, where the breakdown time is longer than 1.8 $\mu$ sec., the $V-t$ curve for type 1) is lowest, one for type 3) is middle, and the breadown voltage for type 2) is highest. It is considered that such a relation of three $V-t$ curves comes from the reason why the length of the insulator chain (1330 mm) is longer than the length of the arcing horn gap (1130mm). The difference of these distances is just the depth of the overlapping arcing horn (200mm).

Comparing types 1) and 3), where breakdowns occur also at the arcing horn, the breakdown voltage for type 1) is a little lower than that for type 3) because of the effects of the distortion of the electric field due to the conducting parts of the insulator chain and others.

In both figures, the breakdown voltages become very high where the breakdown occurs in a shorter time than the crossing point ($T_o$=1.8 $\mu$ sec.). In this region, the $V-t$ curves are located in the order of types 1), 2) and 3), where the order is reversed as compared with the case of the region of longer times than $T_o$. In this short time region, the fiashover creeps on the surface of the insulator chain, namely, a critical cascading fiashover occurs. as indicated by the mark "*" in Figs. 6 and 7.

The differences between $V-t$ curves due to the polarity of the applied voltage change depending on breakdown time lag. In the range of longer time lag than $T_o$, the positive breakdown voltage is lower than the negative one, and vice versa. It is considered that these differences in $V-t$ charactristic come from the fact that the positive corona becomes longer than the negative one. In the range of shorter time long than $T_o$, the $V-t$ characteristic is only slightly dependent on the polarity. However, for the positive applied voltage, the $V-t$ curves in the three types of test apparatus change apparently their order of these breakdown voltages. For the negative voltage, however, the $V-t$ curves in the three type electrodes don't have any apparent difference.

Here, it is deduced that creepage phenomena occur when the relation between the fiashover voltages at the horn gap in air and on the surface of insulator reverses on time lag $T_o$ and also when the applied voltage is very high and has a steep wave front such as 1833 kV/$\mu$ sec. or more. The minimum voltages to obtain a critical cascading fiashover are arranged in the lower column on Table 3. The positive $V_{50}$ in the arcing horn gap and a cascading fiashover on the insulator chain is shown in the table.

Table 3. The List of the Critical Cascading Flashover Voltages

| Polarity | Casc. Flash. Volt. (kV) | 50% Casc. Flash. Volt. (kV) |
|---|---|---|
| Positive | 1, 140 | 1, 202 |
| Negative | 1, 134 | |

The phenomenon of the critical cascading fiashover is shown in Fig. 3. The

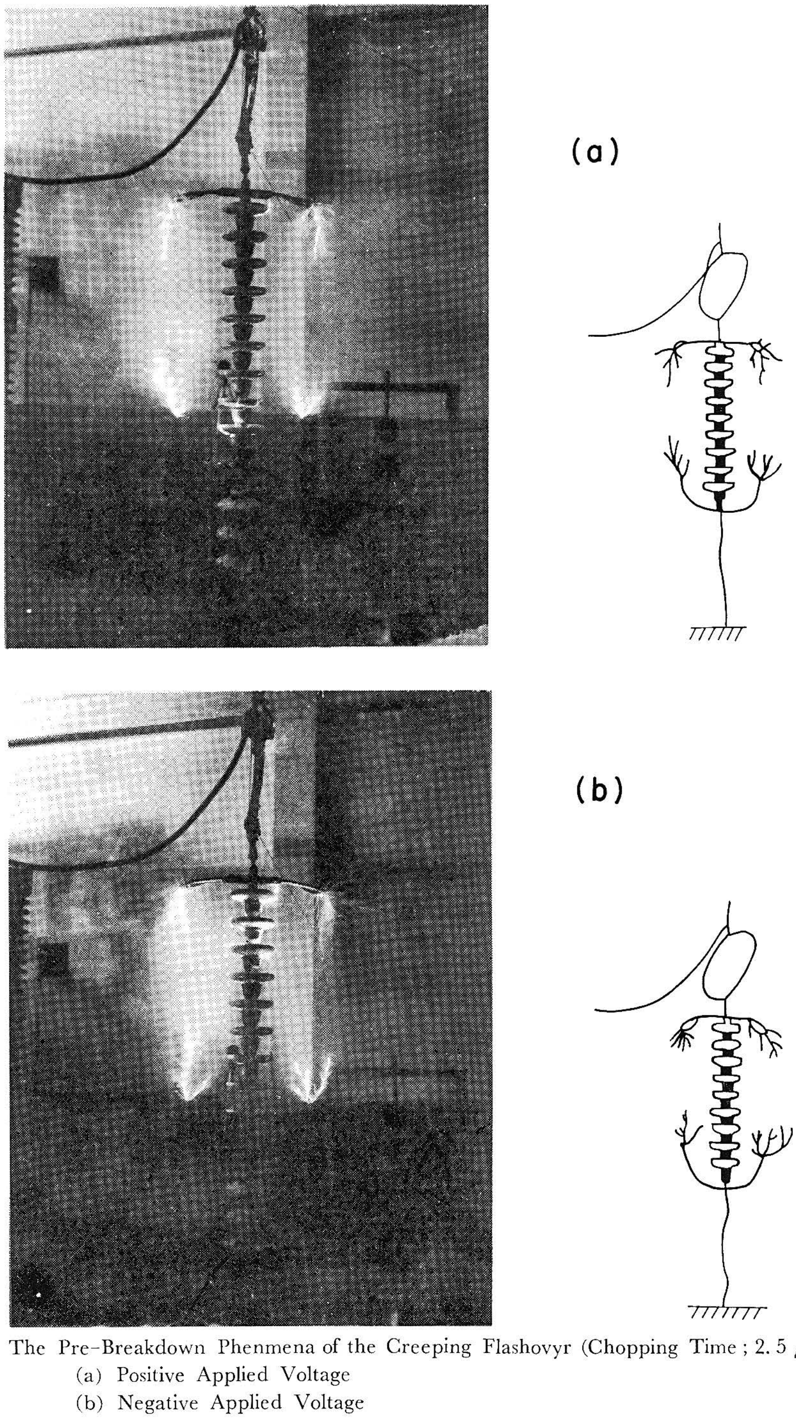



Fig. 8. The Pre-Breakdown Phenmena of the Creeping Flashovyr (Chopping Time ; 2. 5 $\mu$ sec.)
(a) Positive Applied Voltage
(b) Negative Applied Voltage

photograph as shown in the figure was taken under the conditions that the applied voltage was positive 1200 kV, about 1.8 times as much as $V_{50}$ of the insulator assembly and the breakdown time was $T_b=0.8$ $\mu$sec..

Furthermore, a pre-breakdown corona was observed before an ordinary fiashover by means of the chopping voltage method. Unfortunately, in these experiments, the propagating streamer couldn't be observed in the case of critical cascading breakdown phenomena, because, the breakdown time lag was very short and it couldn't be chopped. A picture under the conditions of negative voltage application and a chopping time of $T_c=1.5$ $\mu$ sec. is shown in Fig. 8. In the figure, many corona growing on the whole surface, and a growing loader stage corona from the sharp horn tip on the earth side can be seen. It is especially remarkable that surface corona begin to grow on the surface of the insulator at the negative high voltage side.

These phenomena come from the reason why the depth of the overlapping horn was shallow, and the voltage shared by each insulator became larger at the high voltage side. Hence, the surface corona does not start from the positive voltage side on which the corona inception is easy, but not from the negative voltage side. Even if the ordinary breakdown path occurred in the negative voltage side, the arc path would not complete. When the applied voltage is much higher than a critical fiashover voltage, the surface corona grows very well, and a critical cascading fiashover occurs without fail.

## 4. Conclusion

In this experiment, conditions for an occurrance of critical cascading fiashover on the utility assembly have been obtained as follows;

(1) Critical cascading fiashovers occur when a high over-voltage enurgh having a steep wave front of such as 1833 kV/$\mu$ sec. or more is applied to the insulator assembly.

(2) Critical cascading fiashovers occur in a very short lag time ($T_e=1.8$ $\mu$ sec.) or less.

(3) The surface corona growing up to the main arc path start from the relatively negative side, even if a voltage application is for either positive polarity or negative.

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