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ULTRA-HIGH SPEED PROTECTION DEVICE —FUJI ULTRUP FUSE

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I. INTRODUCTION

The increasing scale of equipment in keeping with recent rises in power requirements has resulted in relatively large short circuit capacities. In this connection, there are two problems. This first problem is the high costs and considerable space needed by all the necessary equipment such as breakers against the large circuit capacity. The second problem is the wide extent of the damage which results since the original faults spread easily due to the vast amount of energy which occurs during a short circuit fault.

In order to solve these problems, it is most desirable to have protective equipment with a high level of current limiting action in order to minimize the high magnetic and thermal stress caused by the short circuit current and with high economy and sufficient current carrying capacity.

In the past, such protective equipment was almost non-existant and that which existed was highly specialized, which meant that equipment costs were extremely high. It is very difficult to produce high voltage current limiting fuses having sufficiently high current-carrying capacity and even when they can be produced, the current limiting effects are greatly reduced.

Fuji Electric has originally developed and started manufacturing a short circuit protection device known as the ULTRUP FUSE with ultra-high speed interruption and high level current limiting action by combining a special electric detonator and semiconductor elements. Several hundreds of these devices have already proven their effectiveness in Japan.

II. BASIC INTERRUTION PRINCIPLES OF THE ULTRUP FUSE

In ordinary current limiting fuses, the cross sectional area of the fuse element must be large so that rated current value can be increased. This causes the melting time to increase and the cut-off current increases roughly in proportion to the rated current value, while the clearing I^2t increases at a rate about 2.5th power of the rated current. Therefore, the protective characteristics rapidly de-

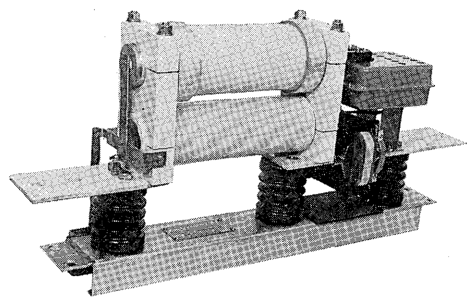


Fig. 1 3.5 kV, 1,200 A FUJI ULTRUP FUSE

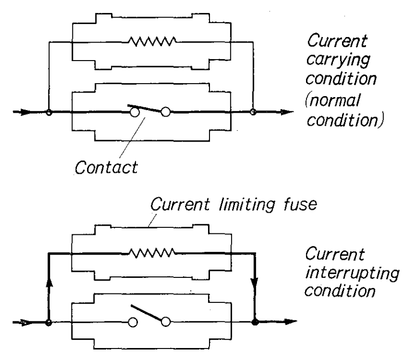


Fig. 2 Fundamental principle

teriorate and basically such characteristics can not be avoided.

One method for interruption with a large rated current, low cut-off current and low clearing I^2t is to separate the current carrying and interrupting functions as shown in *Fig. 2*, by connecting a current limiting fuse with a low rated current in parallel with contacts so that current carrying is performed by the contacts and interruption is performed by the current limiting fuse when the contact are open. The ULTRUP FUSE operates according to this fundamental principle. However, in order to make this basic principle effective, the contacts have to be opened at very high speeds with no delays and for this reason the ULTRUP FUSE employs a newly developed special electric detonator driving capsule (produced by Asahi Chemical Industry Co., Ltd.). The electrical energy for ignition of this capsule is the energy of the short circuit current in the ULTRUP FUSE itself and control is performed by semiconductors.

III. RATINGS AND SPECIFICATIONS

Table 1 **General specifications of ULTRUP FUSE**

Model \ Item	Rating			Example of characteristics		Weight (kg)
	Voltage	Current (A)	Interrupting capacity	Max. peak let-thru. current (kA)	Working current (kA)	
UF11A/06/20	500 V	2000	100 kA	43	20	12
UF11A/06/40		4000	100 kA	43	20	25
UF11A/3/6	3.6 kV	600	MVA 400	19	8	13
UF11A/3/12		1200	400	19	8	14
UF11A/3/20		2000	300	30	15	40
UF11A/6/6	7.2 kV	600	MVA 500	17	8	15
UF11A/6/12		1200	500	17	8	16
UF11A/6/12		2000	350	21	12	43

The standard specifications for 600 V, 3.6 kV and 7.2 kg types are shown in *Table 1*. In addition to the types shown here, it is also possible to manufacture fuses with larger current capacities, larger breaking capacities and those based on NEMA standards (less than 5.5 kV).

IV. CONSTRUCTION AND OPERATION

The basic construction of the ULTRUP FUSE is shown in *Fig. 3*. There is a trigger cylinder which has current carrying functions under normal conditions and the contacts of it are openend by the explosive energy of the driving capsule. A current limiting fuse with a low rated current is connected in parallel with trigger cylinder. After operation these two have to be renewed. The equipment consists of a current transformer located in the conductor to pick up the short circuit current, a detector on the conductor which controls the current transformer output and supplies ignition current to the driving capsule at suitable times, insulators to support the detector and conductors, a base and an interruption indicator. *Fig. 4* shows the electrical circuitry of the ULTRUP FUSE. The detector consists of a capacitor, resistor, silicon symmetrical switch (SSS) and an ignition transformer. The operation is as follows.

First, under normal conditions, the current transformer output current i flows in the resistor and the voltage e which is proportional to the main circuit current I arises across the resistor. Since the voltage e is somewhat lower than the breakover voltage V_{B0} of the SSS at this time, the SSS remains in the OFF state. Therefore, the driving capsule is not ignited and the ULTRUP FUSE does not operate. Under such conditions, there is almost no current flowing in the current limiting fuse. The SSS characteristics are shown in *Fig. 5*. When a short circuit fault occurs, I increases rapidly, e also increases proportionally and exceeds the V_{B0} of the SSS. When this happens, the SSS immediately breaks over and enters the ON state. A part of the current transformer output current flows into the ignition transformer which supplies a detection pulse (ignition current) to the driving capsule.

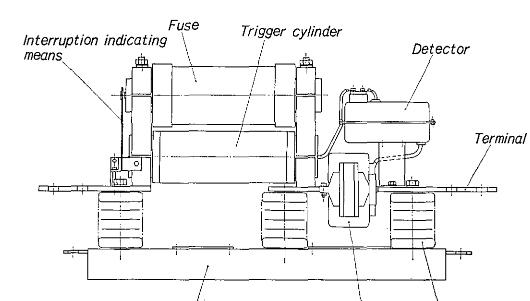


Fig. 3 Construction of ULTRUP FUSE

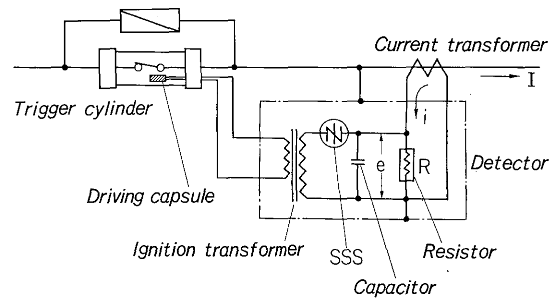


Fig. 4 Connection diagram of ULTRUP FUSE

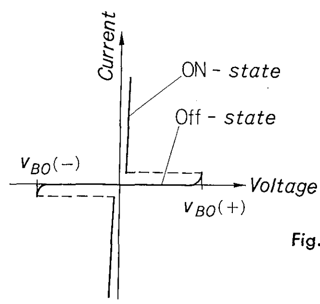


Fig. 5 Characteristics of SSS

When this occurs, the driving capsule is operated immediately to open the trigger cylinder completely. The main circuit current I is then momentarily commutated by the current limiting fuse. Since a large current is suddenly flowing in the current limiting fuse, it soon melts and the current is interrupted to the current limiting action.

The time at which the SSS breaks over, i.e. the time required after the ULTRUP FUSE detects the short circuit current until the trigger cylinder is completely open is less than 200 μs and the time until the current limiting fuse melts is approximately 300 μs, both of which are extremely short.

The current waveform at the time of breaking is as shown in *Fig. 6*. The working current I_W of the ULTRUP FUSE can be obtained from the following equation :

$$I_W = \frac{V_{B0} \cdot N}{R}$$

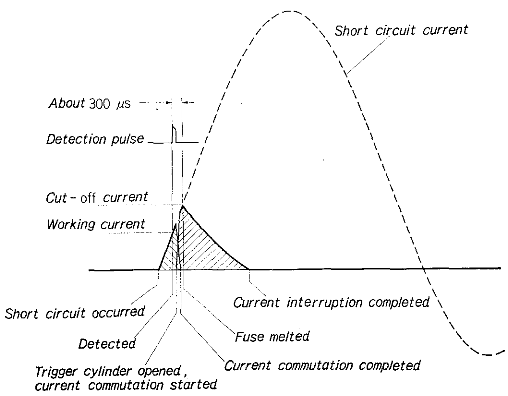


Fig. 6 **Waveform in interruption**

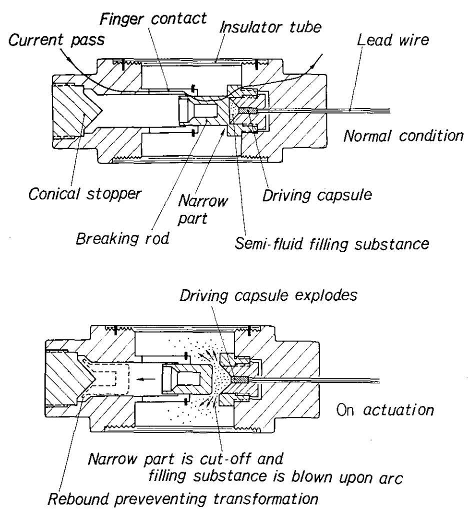


Fig. 7 **Construction and actuation process of trigger cylinder**

where V_{B0}: SSS breakover voltage (V)
N: current transformer turn ratio
R: resistance of the resistor (Ω)

This value can be set to the desired working current by varying the resistance. The working current is normally from 5 to 15 times the rated current and it is determined from the rush current and short circuit capacity of the circuits used as well as the protected equipment withstand capacity.

The trigger cylinder is the most important part of the ULTRUP FUSE. It acts to break the current path at ultra high speeds by means of the explosive energy of the driving capsule. The construction and conditions during operation are shown in *Fig. 7*. The narrow part of the breaking rod is cut by the explosive power of the driving capsule. The separated part is subjected to a large force which pushes this to the left. When the breaking rod is cut, i.e. when the contacts are completely open, the semi-fluid filler is ejected and is blown against the arc which arises so that current commutation becomes easy. The separated part is moved into the finger contact where is strikes the conical stopper. As the dotted line shows, the front tip shape is changed so that it is caught and recoil is completely prevented.

Since the trigger cylinder has sufficient strength, there is no breakage or deformations during operation and the operating sound is very low. Therefore, there is no problem of safety even in the presence of explosive sparks.

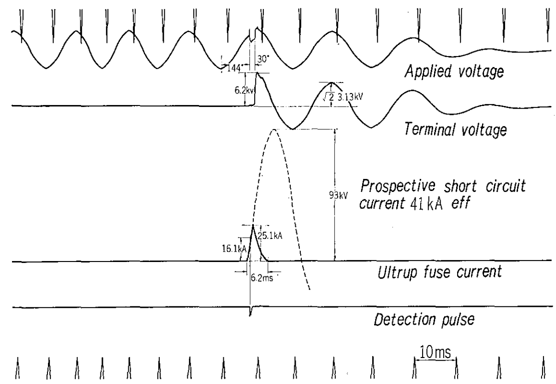


Fig. 8 **Oscillogram of short circuit test**

Fig. 8 shows a typical oscillogram at the time of interrupting a short circuit current by the ULTRUP FUSE. As is evident from this oscillogram, a 3.6 kV, 2,000A ULTRUP FUSE with a set working current of 16 kA interrupts with a current limiting value of 25.1kA. When comparing these values with the current limiting values of standard current limiting fuses, it is equivalent to a rated current of 150 A and therefore, when considering breaking equipment with an ULTRUP FSUE with a rated current of 2,000 A, it is evident that this is an extremely low value.

V. FEATURE

The ULTRUP FUSE has the following features which were not possible in previous protective equipment.

1) Ultra-high speed breaking

The time from detection of the short circuit current until the start of current limiting is 250 to 300 μs and complete interruption is normally within 1/3 cycle.

2) The current limiting value and clearing $I^2 t$ is very low

When comparing with current limiting fuses with the same current ratings, the current limiting values are 1/2.5 to 1/5 and the clearing $I^2 t$ are 1/10 to 1/50 of the usual values.

Table 2 shows a comparison of the characteristics of interruption with various types of breaking devices in condition of 7.2 kV and 33 kA (single phase). Generally speaking, the ULTRUP FUSE can handle faults with approximately 1/40 of the magnetic stress and approximately 1/1000 the thermal stress of ordinary circuit breakers. In this way, the explosion fires caused by faults in oil-filled devices as shown in *Fig. 9* are completely eliminated.

3) Current carrying capacity is large

The current carrying capacity is 600 to 2,000 A (standard) or 3,000 to 5,000 A (non standard)

4) Breaking capacity is large (refer to *Table 1*)

Table 2 **Comparison of protective ability**

	ULTRUP FUSE (1200A) ※1	Current-limiting fuse (400A)	Circuit breaker
Breaking time (cycles)	Less than ⅓	⅓~1	10 ※2
Max. peak let-thru current (kA)	13.6	49	82.5
Ratio of magnetic stress	1	13	36.8
Cleariug I^2t (A^2S)	0.3×10^6	9.5×10^6	250×10^6
Ratio of thermal stress	1	31.6	834

Condition: 7.2 kV (single phase)
※1 Working current: 6 kA
※2 Reray time of 2 cycles has been taken into account

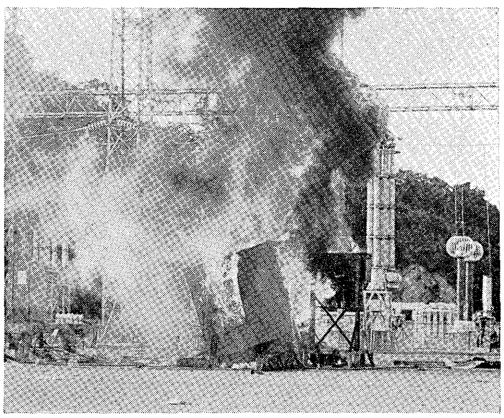


Fig. 9 Catching fire of oil-filled apparatus

5) The working current can be regulated so that appropriate coordination with other devices is possible.

6) Construction is simple and reliability is high.

7) The equipment is light weight and operation is completely automatic. Therefore, it can be handled as an ordinary current limiting fuse.

VI. APPLICATION

The advantages of using the ULTRUP FUSE are that it generally enables economic system construction and the protective level of the system can be increased considerably. The reason for this, as was mentioned previously, is the handling of faults at extremely low magnetic and thermal stresses, and therefore all apparatuses which are connected in series with the ULTRUP FUSE such as switchgears, current transformers cables and disconnecting switches having relatively low thermal and magnetic withstand values can be used. For example, even in the case of short circuit capacity is 400 MVA at 3.6 kV, it is sufficient if apparatuses on the load side have a strength of around 50 MVA.

For this reason, the construction is extremely economical. In addition, the amount of damage when a fault occurs is very small and the costs of restoration are very low. Since the time for decrease of voltage during faults when the ULTRUP FUSE is used is very short, i.e. 2 to 3 msec., all influence from other feeders such as tripping of the magnetic contactor for control of the motor is eliminated.

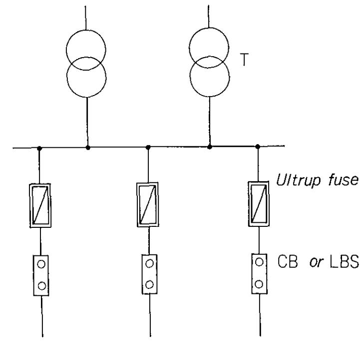


Fig. 10 **Application for feeder protection**

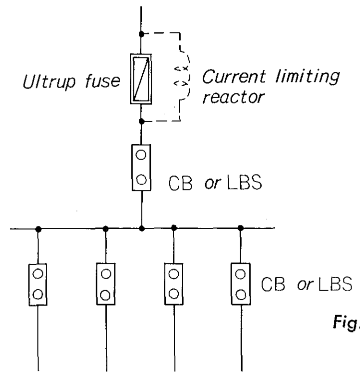


Fig. 11 **Application for lumped circuit of feeders**

Fig. 10 shows the case when the fuse is used for feeder protection, and is employed in conjunction with a low capacity breaker or load break switch.

Fig. 11 shows that it is possible to use low capacity feeder protection devices for overall feeder protection and that the ULTRUP FUSE is very effective when used for protection of groups of motors. In order to prevent complete feeder power interruption due to a fault in one feeder, it is sufficient to connect a current limiting reactor in parallel with the ULTRUP FUSE as is shown in the figure.

Fig. 12(a) shows the fuse which is connected to a bus line for parallel operation at various sources. When comparing between connections made with circuit breakers and with current limiting reactors, this system has the following advantages. In the case of a breaker, the short circuit capacity on the feeder side becomes the sum of both the power sources and even when the breaker for bus tie is opened before the breaker on the feeder side, it is impossible to prevent a momentary inflow to the feeder of the short circuit current from the power sources. Therefore, it is necessary that the feeder breaker is able to withstand at least the sum of the inflow of short circuit current from both power sources, and this means that normally it is necessary to have a breaker which can interrupt such a large short circuit current.

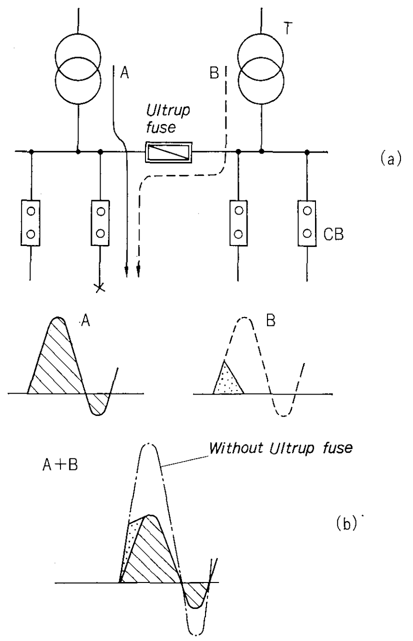


Fig. 12 Application for bus ties

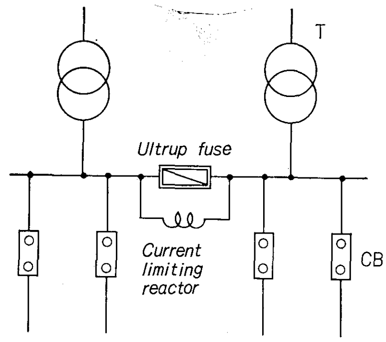


Fig. 13 Application for bus ties (current limiting reactor is connected in parallel)

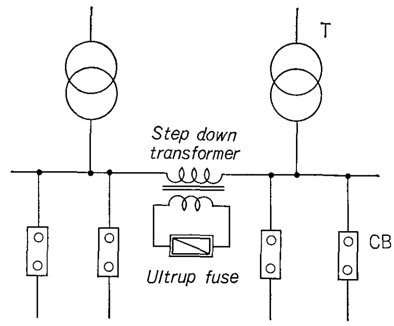


Fig. 14 Application for bus ties (in higher voltage systemthan the rated voltage of ULTRUP FUSE)

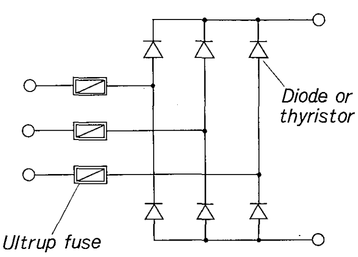
If connected to the current limiting reactor, the feeder short circuit capacity can be reduced but the degree of voltage stability is reduced and the equipment costs become very high. If the bus line connection is made by means of an ULTRUP FUSE, completely parallel connections are possible and both power sources are separated very rapidly when a short circuit fault occurrs.

As can be seen from *Fig. 12* (*b*), the short circuit of the feeder is limited to the short circuit capacity of the power source connected directly to the feeder. Therefore, many breakers and other apparatuses having relatively small withstand or breaking capacity can be used for feeders and highly economical results are obtained. As can be seen in *Fig 13*, it is sufficient to use the current limiting reactor when a disadvantage arises due to complete separation of both power sources. When the voltage is high, step down by a transformer as shown in *Fig. 14* is sufficient.

The ULTRUP FUSE can also be effectively used for the protection of semiconductors. Since thyristor and diode capacities have increased and it has become possible to use elements with low current capacities for comparatively large currents due to the progress of cooling technology, it has become very difficult to provide protective coordination with fuses during short circuits. It is almost impossible to pro vide protective coordination during short circuits in elements with rated currents of 400t o 600 A or over.

Since the clearing I^2t is very low in ULTRUP FUSE even over wide ranges of rated currents as can be seen in *Fig. 15*, it is possible to provide complete protective coordination with semiconductors. *Fig. 16* shows an example of the ULTRUP FUSE used as line fuse.

In addition to the above applications, the ULTRUP FUSE can also be used for low voltage network distribution systems, for electric rolling stock and for ships. The ULTRUP FUSEs described up to now, have been basically the instantaneous value operation type but by changing the detector slightly, it is also possible to manufacture types which operate in respect to the following:



※1: Interruption current (rms)
※2: Working current is 5 times of rated current

Fig. 16 Application for semiconductor protection (line fuse)

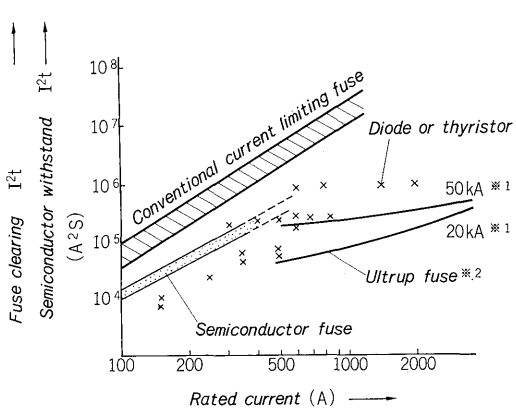


Fig. 15 Protection coordination of large capacity semiconductors

a) Rising rate of current b) Overload current
c) Reverse current for DC

Each of these types can have its own individual characteristics.

VII. CONCLUSION

This article has introduced the completely new protection device ULTRUP FUSE. Through utilization of the various characteristics of the ULTRUP FUSEs, it is possible to achieve economic system construction, provide highly effective short circuit protection in existing systems, improve operational reliability and eliminate damage due to explosion fires in equipment.