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OVERCURRENT PROTECTION COORDINATION FOR HIGH TENSION CUSTOMER'S EQUIPMENT

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I. INTRODUCTION

In recent years, electric power requirements of all types from heavy industrial plants to ordinary households have increased remarkably. The number of high tension customers has also risen accordingly. This is due to the fact that the power supply system in Japan is a high voltage supply with contract demands of 50 kW or over and also the power units are increasing along with the greater popularity of heating and air conditioning equipment, elevators, labor saving devices and office machines. In addition, in the facilities of high tension customers, there has been a tendency to emphasize only the economic aspects, to use equipment of a comparatively low level and not to investigate carefully coordination of protection. Therefore, the so-called extensive faults in which the complete power supply is interrupted by faults in the customer's equipment have reached a level of about 20% recently, and this has resulted in a new social problem. Measures against such faults are being seriously investigated from the system side and gradually being enforced. For example, one aspect of these measures hes been the establishment of a Japaaese Industrial Standard (JIS) for Cubicle Type Unit Substations for 6.6 kV Receiving and the enforcement of this as a Japan recommendation system.

Measures from many angles are required to eliminate these extensive faults. This article describes basic considerations concerning overcurrent protection.

II. PROTECTION COORDINATION REQUIREMENTS

It is essential to choose and provide protective equipment such as relays, breakers and fuses in such a way that when a fault occurs in the system, the range of the fault can be kept to a minimum within the circuit concerned.

Fig. 1 shows the skeleton diagram of a typical high voltage distribution line. There are both aerial and underground distribution systems, but in Japan, the aerial system is much more prevalent. In both cases, supply transformers for low tension customers (power company equipment) and those for high tension customers exist together in the same line. If a fault should occur in such as system at the point Cf of the high tension customer C an overcurrent relay (hereafter abbreviated as OCR) and incoming circuit breaker (hereafter abbreviated as CB) of customer C must operate to prevent the occurrence of an extensive fault, and the fault current must be eliminated before operation of the #1 feeder OCR in the electric power company's distribution substation (hereafter abbreviated as DSS).

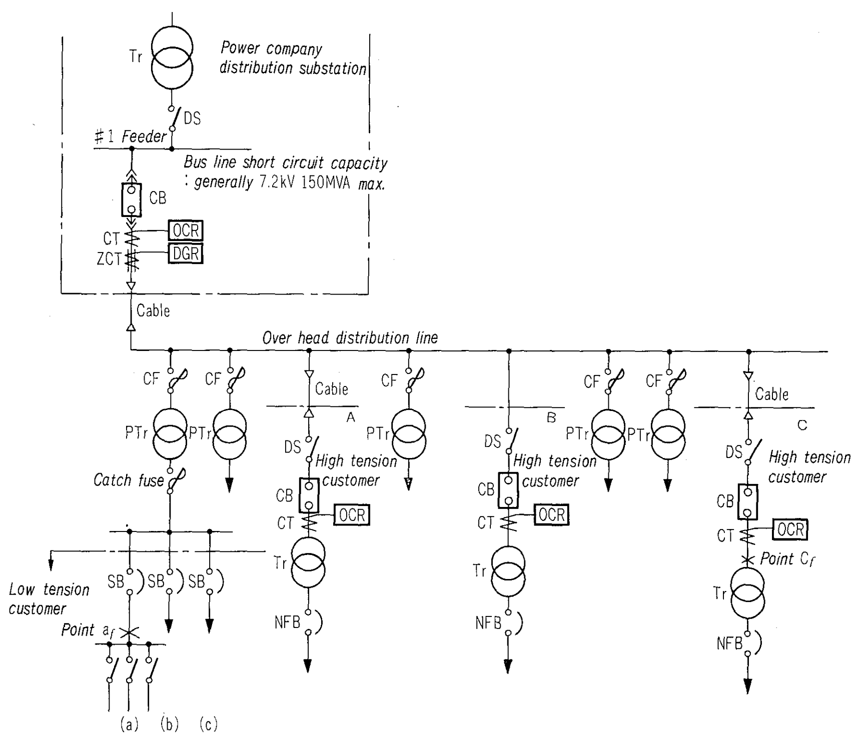

Fig. 1 Skeleton diagram of distribution line

Table 1 **Lapse of accident at non-utility electric installation and distribution line**

Item \ Year	1962	1963	1964	1965	1966	1967	1968
Distribution line supply fault (A)	37,703	28,741	30,893	33,034	20,306	16,696	11,626
Specific electrical facilities' extensive fault (B)	3,750	2,811	2,211	3,345	2,799	2,661	2,144
B/A (%)	9.9	9.8	7.2	10.1	13.8	15.9	18.4

When a fault occurs at the af point of the low tension customer, the fault current must be eliminated by safety breaker SB operating prior to operation of the catch fuse on the secondary side or the cutout fuse CF on the primary side of the pole transformer in the upper level protection equipment. Naturally, it is also necessary that operation of the catch fuse or cutout fuse be faster than that of the DSS OCR.

If operation of this protective equipment is not sufficiently coordinated with that of the DSS OCR, the entire ♯1 feeder shown in *Fig. 1* will be interrupted. Faults in which a fault in the customer's equipment causes interruption of the entire system are generally known as extensive faults. These extensive faults occur not only because of incomplete protection coordination as mentioned above but also due to faults at the cable ends and disconnecting switch in the power supply devices in the protection equiment and faults in the individual protection units such as the CB, CT and OCR. However, it is still essential to establish protection coordination beforehand so that an extensive fault will never occur when the protective equipment is operating normally.

Table 1 shows the annual number of extensive faults from 1962 to 1968. It is clear from this table that even though the number of faults are decreasing year by year as the power companies strengthen their own equipment, the number of faults in the customers' equipment is not decreasing and there are many cases where extensive faults occur. Therefore, the percentage of extensive faults is increasing every year and recently it has reached about 20%. There are three main measures to eliminate extensive faults:

(1) The characteristics of equipment such as the CB, DS, PF, PCT and ZCT (use molded type and be careful about corona characteristics) must be carefully investigated and highly reliable devices must be used. An insulation class of 6 A must be employed.

(2) Protection coordination must be established.

(3) Special care must be taken with work, especially when handling the ends of the cables.

All three of these measures along with proper maintenance are necessary. Concerning measure (1) it is essential to choose highly reliable equipment not only from the viewpoint of economy but also considering troubles caused to other customers.

III. CIRCUIT CONSTRUCTION AND OVERCURRENT PROTECTION SYSTEM

Although it would seem simple at a glance, the circuit construction for high voltage customers in actually highly diversified. However, it can be arranged into three basic types as specified in the Japanese Industrial Standard on Cubicle Type Unit Substa-

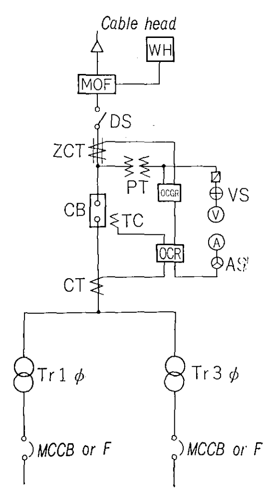

Fig. 2 **Skeleton diagram of CB type cubicle**

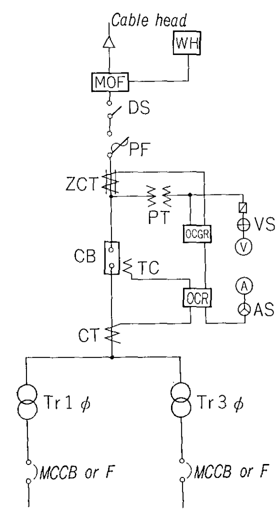

Fig. 3 **Skeleton diagram of PF • CB type cubicle**

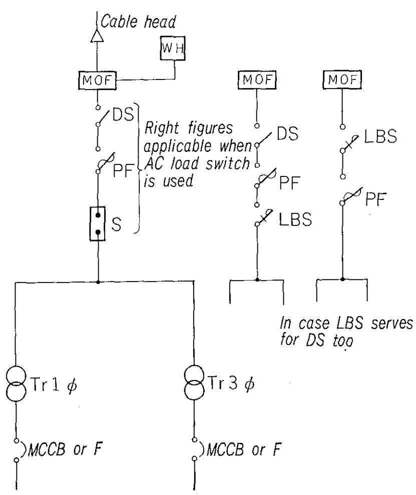

Fig. 4 **Skeleton diagram of PF • S type cubicle**

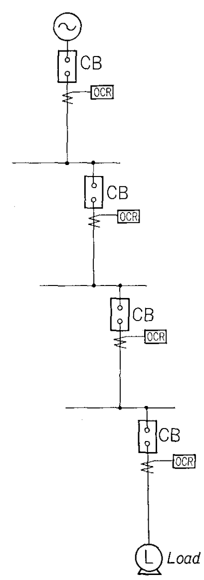

Fig. 5 **Time delay distribution system**

tions for 6.6 kV Receiving:
(1) CB type (refer to *Fig. 2*)
(2) PF・CB type (refer to *Fig. 3*)
(3) PF・S type (refer to *Fig. 4*)

The protection systems used in these three types are described below.

(1) CB type

This is the basic type of power system protection and can be used for complete protection agninst overload, short circuit, ground and other fault. A relay is employed in combination with a circuit breaker (CB).

(2) PF・CB type

Since the CB type is highly expensive, this type is merely the CB type made more compact for economical reasons by using a power fuse (hereafter abbreviated as PF) for protection against low-probability short circuits. Protective functions are exactly the same as those of the CB type.

(3) PF・S type

This system is more economical since it provides protection by means of a combination of PF and AC load break switch (hereafter abbreviated as S). However, with this type, part of the protective capacity is sacrificed in favor of economy. In other words, since the S does not have an automatic tripping device, overload and ground fault protection is not possible. This can be remedied by the addition of an automatic tripping device for the S but it is necessary to consider protection coordsnation with the PF and obtain constant breaking capability. This point will be discussed later.

(4) Overcurrent protection system

There are two types of overcurrent protection systems for power lines: the stepped time delay system and the zone protection system. The former is the basic system and even when the latter high level system is employed in main relay systems, the former is also used for protection of subsequent equipment. It is no exaggeration to say that the former system is employed without exception for the protection of high tension customers' equipment. The concepts of this system are as follows.

The complex network of the system can be simplified as shown in *Fig. 5*. Power is supplied from the power station to the load in various steps. An OCR and CB are arranged at each step and the operating time limits of the OCR's are made successively longer so that equation (1) is satisfied from the load side to the power station. In this way, selective breaking of the fault range in respect to time is possible and the fault range can be kept to a minimnm.

$$kT_{Ry1} > T_{Ry2} + T_{B2C} \quad \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

where T_{Ry1}: upper level OCR operating time (s)
T_{Ry2}: lower level OCR operating time (s)
T_{CB2}: lower level CB maximum operating time (s)
k: inertia coefficient of upper level OCR

In this system, protection coordination is difficult when there are many steps. Since high tension customers are at the terminal points of the power system, high speed operation is required from the relation with the DSS OCR on the one hand but on the other hand, more technical difficulties are encountered because of load device surge currents, coordination with tension protective equipment, etc.

IV. FAULT CURRENT CALCULATION

When investigating protection coordination, it is always necessary to select the various types and ratings of protective devices as well as their set values by calculating the fault current. The fault currents when there are short circuit faults at points F_1 to F_4 in *Fig. 6* are given be equations (2) to (5).

$$I_{S1} = \frac{Q \times 10^3}{\sqrt{3} \times 6.6} \quad \cdots\cdots\cdots\cdots (2)$$

$$I_{S2} = I_{S1} \times \frac{\sqrt{3}}{2} \quad \cdots\cdots\cdots\cdots (3)$$

$$I_{S3} = \frac{P_{3\phi}}{\sqrt{3} \times 6.6} \times \frac{100}{Z_l + Z_t} \quad \cdots\cdots\cdots\cdots (4)$$

$$I_{S4} = \frac{P_{1\phi}}{6.6} \times \frac{100}{2Z_l + Z_t} \quad \cdots\cdots\cdots\cdots (5)$$

where: I_{S1}: short circuit current at F_1 (A) 3-phase short circuit
I_{S2}: short circuit current at F_2 (A) single phase short circuit
I_{S3}: short circuit current at F_3 (A) 3-phase short circuit
I_{S4}: short circuit current at F_4 (A) single phase short circuit
Q: short circuit capacity at incoming point (MVA)
$P_{3\phi}$: 3-phase transformer capacity (kVA)
$P_{1\phi}$: single phase transformer capacity (kVA)

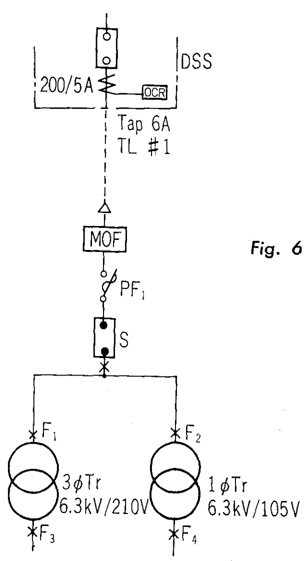

Fig. 6 An example of high-tension incoming

Table 2 **Operating time of overcurrent relay and current limiting fuse**

DSS: CT	DSS: OCR	Contract demand (kW)	Transformer capacity	PF rated current (A)	Transformer % Z	Incoming short circuit capacity	Operating time of protector during short cir. on pr. side of Tr — Fault point F_1 (pr. side of 3 φ Tr): 3 φ short cir. current (kA)	DSS OCR operating time	PF_1 operating time	Fault point F_2 (pr. of 1 φ Tr): 1 φ short cir. current (kA)	DSS OCR operating time	PF_1 operating time	% impedance on pr. side of Tr: 3 φ Tr kVA base	1 φ Tr kVA base	Operating time of protector during short cir. on sec. side of Tr — Fault point F_3 (sec. side of 3 φ Tr): 3 φ short cir. current (A)	DSS OCR operating time	PF_1 operating time	Fault point F_4 (sec. side of 1 φ Tr): 1 φ short cir. current (A)	DSS OCR operating time	PF_1 operating time
200/5 A	Inductive type tap 6 A (equiv. 240 A) lever #1	245	3 φ 300 kVA 1 φ 100 kVA	75	4	150	13.1	0.2	or less 0.01	11.3	0.2	or less 0.01	0.2	0.07	620	0.68	0.3	366	2.2	2.5
						100	8.7	0.2	0.01	7.5	0.2	0.01	0.3	0.1	610	0.69	0.32	361	2.3	2.7
						50	4.4	0.2	0.01	3.8	0.21	0.012	0.6	0.2	570	0.75	0.38	345	2.5	3.0
						25	2.2	0.3	0.025	1.9	0.31	0.03	1.2	0.4	505	0.87	0.6	316	3.5	5.0
				75	2.5	150	13.1	0.2	0.01	11.3	0.2	0.01	0.2	0.07	966	0.49	0.1	574	0.75	0.4
						100	8.7	0.2	0.01	7.5	0.2	0.01	0.3	0.1	935	0.5	0.11	561	0.76	0.43
						50	4.4	0.2	0.01	3.8	0.21	0.012	0.6	0.2	845	0.54	0.14	523	0.81	0.46
						25	2.2	0.3	0.025	1.9	0.31	0.03	1.2	0.4	705	0.61	0.22	459	1.0	0.8
		135	3 φ 150 kVA 1 φ 50 kVA	40	4	150	13.1	0.2	0.01	11.5	0.2	0.01	0.1	0.03	318	3.7	0.17	186	Non operating	1.5
						100	8.7	0.2	0.01	7.5	0.2	0.01	0.15	0.05	315	3.9	0.18	185	Non operating	1.6
						50	4.4	0.2	0.01	3.8	0.21	0.01	0.3	0.1	303	4.2	0.21	180	Non operating	1.8
						25	2.2	0.3	0.01	1.9	0.31	0.01	0.6	0.2	284	6.0	0.28	172	Non operating	2.0
				40	2.5	150	13.1	0.2	0.01	11.5	0.2	0.01	0.1	0.03	501	0.87	0.063	296	5.8	2.4
						100	8.7	0.2	0.01	7.5	0.2	0.01	0.15	0.05	493	0.91	0.065	292	5.9	2.5
						50	4.4	0.2	0.01	3.8	0.21	0.01	0.3	0.1	466	1.0	0.075	280	6.5	2.6
						20	2.2	0.3	0.01	1.9	0.31	0.01	0.6	0.2	421	1.2	0.085	261	7.0	3.4

Z_l : line impedance (%)
Z_t : transformer impedance (%)

The results of the calculations are listed in *Table 2*. In this calculation, changes in the magnitude of the incoming short circuit capacity which are influenced by the line impedance were used for simplification. In other words, with the maximum value of the DSS bus line short circuit capacity as 150 MVA, the incoming short circuit capacity was changed to 150, 100, 50 or 25 MVA depending on the line impedance. The high tension customer's transformer impedance was calculated as either 4% or 2.5%.

Since the fault current exists continuously from the rated current up to the maximum value which can occur at that point, this must be considered when investigating the coordination.

V. INVESTIGATION OF PROTECTION COORDINATION IN PF・S TYPE

Table 2 shows the short circuit currents when there are faults at points F_1 to F_4 in *Fig. 6* and also the operating times of the DSS OCR and the high tension customers' PF. In this table, the current ratio of the CT which decides the DSS OCR operating time, the OCR tap value and the time lever value (hereafter abbreviated as TL value) are typical severe side values taken from the real values of each power company. Fundamentally, it should be possible to select the equipment for coordination on the basis of such a numerical investigation but when the DSS side must be set according to restrictions from the upper level system and the PF is set according to the transient rush current characteristics of the transformer, there are cases where use is impossible since coordination can not be obtained. The values in *Table 2* are also not for all specified fault conditions. Therefore, final confirmation of protection coordidation must be carried out by using the the operating time-current characteristics curves of the OCR and PF. There are three types of PF time-current characteristics as follows:

(1) Fusing time-current characteristics
(2) Total breaking time-current characteristics
(3) Permissible time-current characteristics

However, (2) are used in coordination investigations for the upper level OCR and (3) are used for investigations of coordination with lower level protective equipment.

For example, when an molded case circuit breaker (hereafter abbreviated as MCCB) is used for protection on the secondary side of the transformer, the fault range at any point must satisfy the stepped time limit principles shown in formulae (6) and (7).

$$kT_{Ry1} > T_{PF2} \quad \cdots\cdots (6)$$

$$T_{PF3} > T_{MCCB} \quad \cdots\cdots (7)$$

where: T_{Ry1} : operating time of DSS OCR (s)
k : coefficient of inertia of OCR
T_{PF2} : max. breaking time of customer's PF (s)
T_{PF3} : permissible non-deterioration time of customer's PF (s)
T_{MCCB} : max. breaking time of MCCB on customer's secondary side (s)

Fig. 7 shows the breaking time-current characteristics of the Fuji Electric HH type PF together with the DSS OCR charactistics under the previously described conditions. There are two types of OCR characteristics: A type and B type. These two types exist mainly because of the operating principles of the induction type over current relays which are

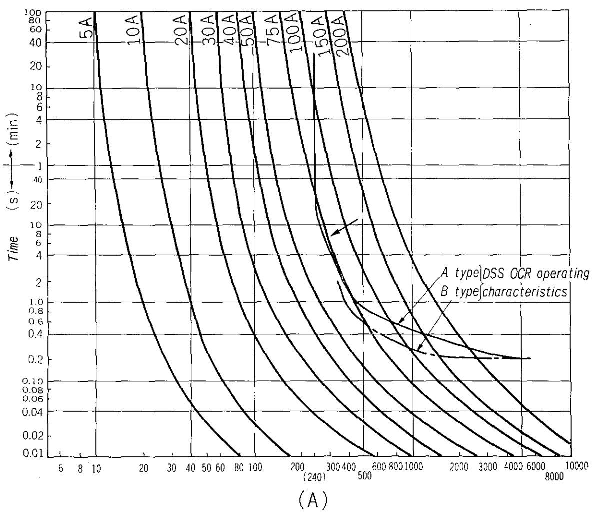

Fig. 7 Coordination of current limiting fuse and overcurrent relay of substation

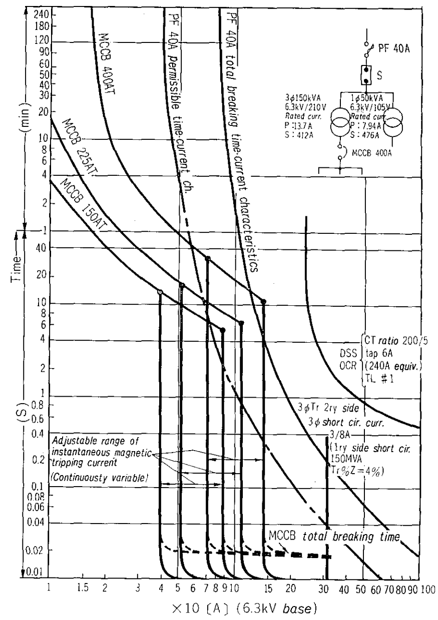

Fig. 8 Coordination of current limiting fuse and load break switch at PF • S type cubicle

manufactured at present in Japan. Since it is not clear which maker's OCR is to be used, it is necessary to achieve coordination in respect to all models.

As is clear from *Fig. 7,* coordination is achieved when the rated PF current is 50 A or less but 75 A or over can not be used since coordination is not possible. In other words, when the capacity is large, the PF • CB type or CB type must be used. An example of the most suitable ratings for coordination in the case of the PF • S type is as follows:

Rated PF current:	50 A
Contract demand:	180 kW
3-phase transformer capacity:	200kVA (250k VA)
Single phase transformer capacity:	75 kVA
Combined transformer capacity:	275 kVA (325 kVA)

The figures in parentheses are non-standard 250 kVA ratings of the three-phase transformer capacity which can not be recommended since they go completely to the PF selection limit. In the JIS on Cubicle-Type Unit Substations for 6.6 kV Receiving, the limit for the PF • S type is given as 300 kVA which is also suitable for protection coordination.

Next, coordination between the PF and MCCB on the secondary side of the transformer will be considered. The principle of this coordination satisfies formula (7). In equipment where the contract demand is 135 kW, the 3-phase transformer capacity is 150 kVA and the single phase transformer capacity 50 kVA, protection coordination of the 3-phase transformer circuit is as shown in *Fig. 8*. The PF rated current was chosen as 40 A considering no deterioration in relation to the transient rush current of transformer. The MCCB is chosen with a rated current of 400 A and a 400 A frame so that there will be no transformer exciting conditions from the secondary side due to the 412 A rated current on the secondary side of the transformer.

As is evident from *Fig. 8,* coordination between the DSS OCR and PF is complete but there is no coordination between the PF and the 400 A rated MCCB. In other words, the MCCB operating characteristics cross the permissible time-current characteristics of the PF and cut-off is not possible when the MCCB instantantaneous tripping current range is a minimum. When MCCB with ratings of 225 A and 150 A are investigated, coordination becomes possible by adjusting the instantaneous tripping current range. When the MCCB is placed in the main secondary line of the transformer, protection coordination is not possible but is becomes possible if several MCCB's of smaller capacities are located in branch circuits.

This is more or less the same in the case of the fuse. Coordination of the PF and MCCB is not only always possible in the above example but also in some cases when the MCCB is in the main circuit, although there are cases when it is impossible.

The above mentioned over current protection coordination was investigated for elimination of extensive faults but when the protection of the customer's equipment was also included, the investigations points for the PF • S system were adjusted and the following problems were encountered.

1) Protection coordination between the DSS OCR and the high tension customer PF-MCCB

(1) If the rated PF current is limited to 50 A or less, coordihation with the DSS OCR can be achived.

(2) Coordination of the PF and MCCB is satisfactory as long as the MCCB's are used in branch circuits rather than the main circuit.

2) Equipment overload protection

If the PF rated current is two or three times the equipment rated current for determination from the transient rush current of the transformer, overload protection is not possible. It is necessary to disregard this case when planning the equipment by considering that overloads will never occur. If it is found that overload protection is still required, the S must be provided with an automatic tripping device and a CT and OCR must be added. In this case, there must be protection coordination between the S and PF. A breaking capacity like that described subsequently in section 5) must also be provided.

3) Transformer protection

(1) Overload protection

For the same reason as given in section 2), and also because of the fact that the PF is in a circuit common to both the 3-phase and single phase transformers, overload protection of each transformer by the PF is not possible. Since the MCCB's on the secondary side are in principle located in a branch circuits as was mentioned previously in section 1), it is difficult to select a rated value for overload protection. Therefore, if planning of the equipment is carried out as in section 2) and it is found that protection is necessary, then it is sufficient to provide protection by using a thermal relay and inserting a CT in the low tension side where there is no need to worry about transformer oil temperature detection or insulation problems.

(2) Short circuit protection

The transformer is strong enough to withstand 25 times the rated current for two seconds. Therefore, when the PF breaking time during a short circuit at points F_3 and F_4 is determined and is found to be in excess, PF's are inserted in each transformer or the insulation between the transformer and the MCCB's in the branch circuits on the secondary side is strengthened. Since the distance between them is very small, there is very little probability that faults will occur.

4) PF breaking capacity

In the PF・S type, when there is a fault between the PF and MCCB, the PF operates in respect to any fault current value from the rated load current to the complete short circuit current. The fault current exists continuously due to the line impedance, the impedance of the customer's transformer and the fault point impedance as can be seen from *Table 2*. Therefore, it is dangerous to use an ordinary PF in which breaking is impossible in small current ranges. A PF with full range breaking characteristics must always be used. If such a PF with full range breaking characteristics can not be used, it is necessary to add an automatic tripping device to the S so that the S can handle the uncapable range of breaking of PF. The same way of thinking applies to the PF・CB type.

5) Ground fault protection

Ground fault protection requires that the S be provided with an automatic tripping mechanism. In such a case, the simple single phase line-to-ground fault current is reduced to the level of only a few amperes but when there is an inter-phase ground fault, a current flows which is equal to the short circuit current. This inter-phase ground fault current is altered considerably depending on the values of the line impedance and the resistance at the grounding point. In the CB type, the most recent types of CB are able to handle inter-phhse ground fault currents and there is no problem.

To counteract this, the switching capacity of S is small generally in comparison with that of the CB and the fault current is handled by dividing it among the PF's. Thus, it is necessary to carefully consider coordination between the combined opening times of the OCGR and S and the fusing time-current characteristics of the PF. *Fig. 9* shows a typical example of protection coordination between the 100 A HH type power fuse and an AC load break switch with a rated current of 200 A and an automatic tripping mechanism attached.

Intersection point P_1 in *Fig. 9* must be less than the switching capacity of S. In other words, S with an automatic tripping device must have an switching capacity of more than that at intersection point P_1.

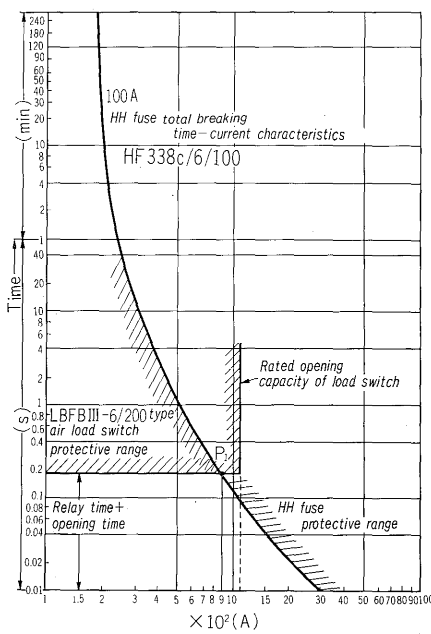

Fig. 9 Coordination of fuse and switch

VI. INVESTIGATION OF PROTECTION COORDINATION IN PF・CB TYPE

When the customer's equipment capacity exceeds about 300 kVA in the PF・S type, coordination can not be obtained between the DSS OCR and the customer's PF and an extensive fault will occur. The range in which coordination is not obtained is shown as the part marked with arrows in *Fig. 7*. In such cases :

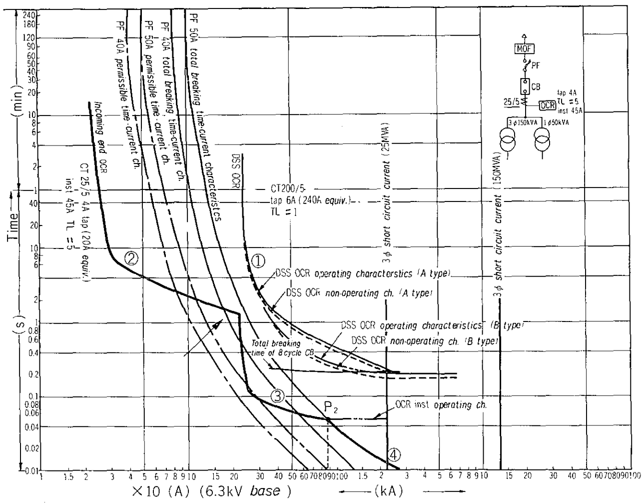

Fig. 10 Coordination of current limiting fuse and circuit breaker at PF • CB type cubicle

(1) In the region marked off by the arrows, the OCR+CB operated more quickly than the DSS OCR.

(2) In the PF • S type, the S is changed to the CB and faults in the overload and light short circuit range are eliminated by the OCR+CB.

(3) Heavy short circuit faults are eliminated by the PF. In such cases, there is no limitation as to the equipment capacity and complete overcurrent protection coordination is possible. This is due to the PF • CB type.

Fig. 10 shows an example of coordination with the DSS OCR. In this case, the DSS of CT and OCR conditions are the same as those in the PF • S system. The conditions of the customer's equipment are as shown in the drawing on the right.

The coordination principle is the "DSS OCR-customer's PF-customer's MCCB". As in the PF • S type, formulae (6) and (7) must be satisfied and the relation among "DSS OCR-customer's (OCR+CB)—customer's MCCB" as in formulae (8) and (9) must also be satisfied.

$$kT_{Ry1} > T_{Ry2} + T_{CB} \quad \cdots\cdots\cdots\cdots\cdots\cdots (8)$$

$$kT_{Ry2} > T_{MCCB} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots (9)$$

where T_{Ry1}: operating time of DSS OCR (s)

T_{Ry2}: operating time of customer's OCR (s)

k: coefficient of inertia of OCR

T_{CB}: max. breaking time of customer's CB (s)

T_{MCCB}: max. breaking time of MCCB on customer's secondary side (s)

The most important thing is that the operating characteristics of the protective equipment on the customer's primary side be in the ②—③—④ curves in *Fig. 10,* i.e. consist of the inverse time operating characteristic part, the instantaneous operating characteristic part and the PF total breaking time-current characteristic part. Coordination investigations are between these combined curves and the DSS OCR and secon dary MCCB. It is sufficient if formulae (6), (7), (8) and (9) are satisfied in the complete range of these curves.

In order to obtain coordination in the part marked off by arrows in *Fig 10,* it is necessary to reduce the TL of the customer's OCR and in practice, the difference with the operating time of the instantaneous element is very small. The PF plays the same or a greater role than the OCR instantaneous element in the CB type and performs high speed breaking in the maximum current range. Therefore, in the PF • CB type, an OCR with an instantaneous element is not required.

In the CB type, if the breaking time of the CB exceeds 5 cycles as desribed later, coordination with the DSS OCR is impossible. But, in the PF • CB type an 8 cycle CB is sufficient since the maximum current range over which coordination is difficultis is protected by the PF.

The above were the main points investigated for overcurrent protecting coordination to prevent extensive faults. However, the following points had to be considered for protection including the customer's equipment.

1) Protecting coordination between the DSS OCR and high tension customer (PF-CB-MCCB).

(1) Coordination is achieved if formulae (6), (7), (8) and (9) are satisfied. This is not limited in respect to equipment capacity as in the case of PF • S type coordination.

(2) As in the PF • S type, coordination with primary side protective equipment can be achieved by placing the MCCB's in branch circuits rather than in the main circuit.

2) Equipment overload protection

For customers whose general contract demand does not reach 500 kw, it is determined as a link in "contract demand-equipment capacity". The incoming OCR setting is determined as follows:

Tap value$\geqq$current value of contract demand$\times 1.5$ $\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$ (10)

$TL \leqq \# 1$ (not prescribed in case of instantaneous element attached) $\cdots\cdots\cdots$ (11)

When thinking from the standpoint of protection, the tap value should be determined from the standpoint of overload protection of customer's equipment. The TL should be determined from such standpoints as protective operation by means of transformer transient inrush current, coordination with the DSS OCR and transformer short circuit protection. For these reasons, there is still a lot of research to be done in the future.

3) Transformer protection

The concepts are the same as for overload and short circuit protection in the PF • S type. Considering overloads, even if the non-operating range of the OCR becomes smaller by the setting described in the preceding section, the overload protection characteristics of the type PF · CB are more disirable than those of the type PF · S. However, Protection of several transformers with common protective equipment becomes more difficult. Therefore, careful investigations are necessary and if protection is found to be required, protective equipment must be installed in each transformer.

4) Ground protection

Such protection can easily be achieved by adding an OCGR. Since the rate of ground faults is remarkably high, there will no doubt be a tendency to use the OCGR in all case.

5) Operation coordination and selection of PF and CB

By using a small capacity CB of less than the short circuit capacity at the site of installation, back-up breaking is performed by the PF. Therefore, it is not only necessary to investigate coordination with the DSS OCR but also to make careful studies concerning the combination of PF and CB. The main points in this respect are as follows.

(1) Operating time coordination (refer to *Fig. 10*)

Intersection point P_2 of the operating time-current characteristic curves for the PF and OCR must satisfy equation (12). The constant n is from 3 to 5 for ordinary PF's. However, Fuji Electric HH type PF's of the 3/6 kV class with rated currents of less than 200 A have full range breaking characteristics and they can be selected on condition that $I_C \leqq I_{RC}$,

$$nI_f \leqq I_C \leqq I_{Rc} \cdots\cdots\cdots\cdots (12)$$

where I_f: PF rated current

I_C: current value at intersection point P_2 of the operating time-current characteristics curves of the PF and OCR

I_{RC}: rated breaking current of the CB

n: constant which indicates the limit of PF small curent breaking performance

(2) Short circuit fault cooperation

High prospective fault currents are interrupted befor the crest value of the first major current loop is reached as shown in *Fig. 11,* the capacity of the combined CB can be small but it is essential to use items for which thermal and mechanical cooperation can be achieved.

(a) Thermal stress invertigations

If the rated short time current and current through time for the CB are I_S and T_S respectively, then the thermal capacity C can be shown by the following equation :

$$C = I_S^2 \cdot T_S \cdots\cdots\cdots\cdots (13)$$

If the thermal energy at the breaking limit of the PF is assumed to have a triangular wave form and the peak value of the let through current is I_P and the breaking time is T_B, then :

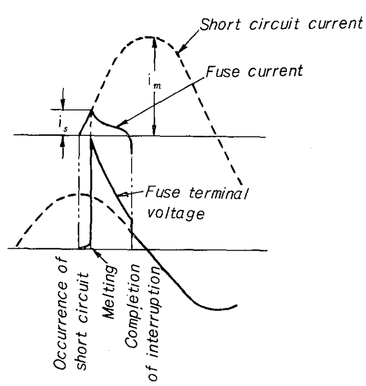

Fig. 11 Oscillogram of current through and voltage across current limiting fuse

$$\int_0^{T_B} (I_P - \frac{I_P}{T_B} t)^2 dt = \frac{1}{3} I_P^2 \cdot T_B \cdots\cdots\cdots\cdots (14)$$

Therefore, selection can be made in accordance with equation (15).

$$I_S^2 \cdot T_S \geqq \frac{1}{3} I_P^2 \cdot T_B \cdots\cdots\cdots\cdots (15)$$

Generally, T_B can be considered as 5 ms.

(b) Mechanical stress

The mechanical stress is determined by the electromagnetic force and the CB must be able to withstand a closing current specified as 2.5 times the maximum breaking current. If this current is I_M and the peak value of the let through current during breaking by the PF is I_P, then the CB can be selected according to the following formula :

$$I_M \geqq I_P \cdots\cdots\cdots\cdots (16)$$

VII. PROTECTION COORDINATION INVESTIGATIONS FOR THE CB TYPE

Protections coordination can be achieved for this system if formulae (8) and (9) are satisfied. More care should be taken concerning coordination in the heavy short circuit region, i.e. formula (8) must be satisfied in the flat operating region of the DSS OCR. When the operating times of each OCR and CB are in the form of a 50 cycle base, then :

DSS OCR 180 ms (200 ms × 0.9)
High tension customer's OCR
(instantaneous element) 20 to 50 ms
Max breaking time of
high tension customer's CB
8 cycle CB 160 ms
5 cycle CB 100 ms

It is evident that if an 8 cycle CB is used, there is the possibility of an extensive fault developing. Therefore, a 5 cycle CB should be used in principle. *Fig. 12* shows an example of coordination in the CB type when the contract demand is 365 kW. Other matters are the same as those described for the PF·CB type.

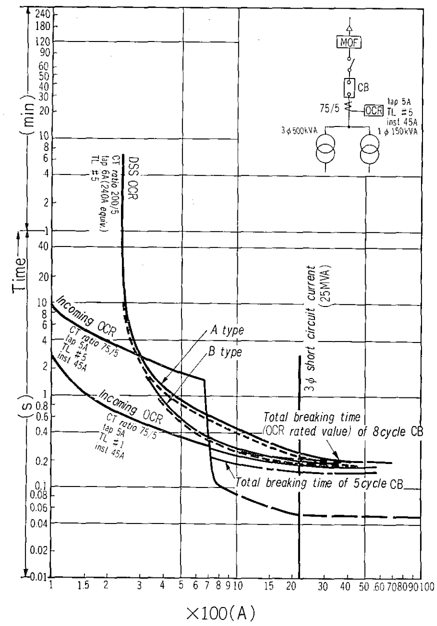

Fig. 12 Coordination of CB type cubicle

VIII. CONCLUSION

This article has given the main points concerning overcurrent protection in order to prevent the development of extensive faults in which the entire system is interrupted by a fault within a high tension customer's equipment. In the future, the importance of electricity will increase and distribution lines will become more complex. Therefore, equipment planning should always include coordination investigations like those described here.

Since the majority of faults are ground faults, appropriate coordination concerning the DSS directional grounding relay (DG) and the high tension customer's OCR in necessary. This was not discussed in this article but the authors hope to describe it in a separate article.

It is hoped that this article will be of use in the planning of high tension customer's equipment in order to eliminate the danger of extensive faults.