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POWER RECEIVING SUBSTATION BY SPOT NETWORK ARRANGEMENT FOR THE KEIO PLAZA HOTEL IN TOKYO

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I. INTRODUCTION

The Keio Plaza Hotel under construction in the Shinjuku area of Tokyo will have 47 stories above ground which will make it the tallest building in the Orient and the tallest hotel in the world. The low voltage network for this building consists of a spot network arrangement and is a 415/240 V 3-phase 4-wire system. Power is sent from one substation underground throughout the skyscraper. The area where the hotel is being built is utilizing the most advanced city planning with all the cooling and heating equipment in one central location, and therefore this spot network type power receiving equipment will not have to supply such energy.

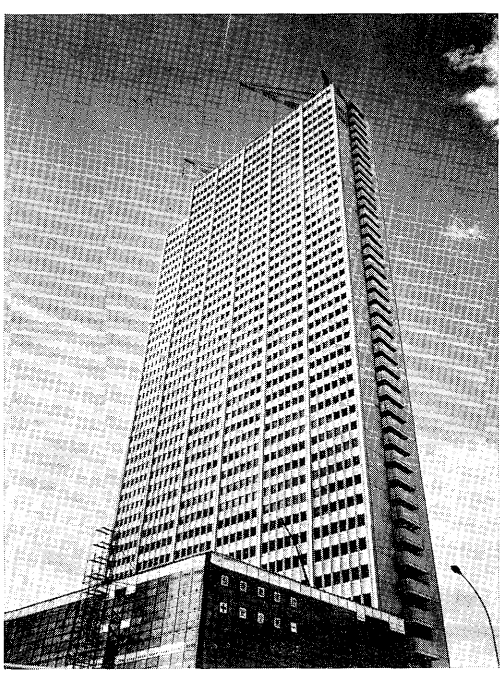


Fig. 1 Outer view of the Keio Plaza Hotel

II. FEATURES OF FUJI LOW VOLTAGE NETWORK COMPONENTS

1) Based on considerable technical experience in the field, Fuji Electric is manufacturing and supplying components for low voltage networks which can be used in both regular and spot networks.

2) There are many soft ware which must be considered in planning low voltage networks and plans must be established completely and rationally. The network system planning is based on practical experience obtained from Europe.

3) The low voltage network components have all undergone such model tests as breaking, short time current and relay tests and the results have been good in all cases.

4) High level techniques of our company based on long years of manufacturing have been concentrated in the high cubicles, breakers, fuses, transformers, watt-meters and relays used in the equipment.

5) A basic feature of the network is that it covers a large capacity and peak load capacity with small rating component.

The low voltage network is known as a "secondary distribution network" in the United States. According to the IEEE Red book, the spot network is used in cases where critical loads divided over a wide range are centralized in one place and when there is no load in the band between the centralized points. In such cases, the spot network is more economical to construct than the regular network. There is very little difference between the operation of the spot network and that of the regular network.

III. SPOT NETWORK OPERATION

1) When a short circuit failure occurs at present in the high voltage cables, the breaker of the feeder concerned is tripped. When the power flows in the reverse direction, the breaker on the low voltage side of the transformer concerned opens, and the reverse flow to the point of failure is stopped. On the other hand the feeder with the failure and the transformer connected to it are cut off from its power distribution system.

This is the reverse power breaking characteristic of the spot network protector. The network can be formed as long as this characteristic is present. It is then possible to take sufficient time in repairing the faulty cable or component. The first low voltage

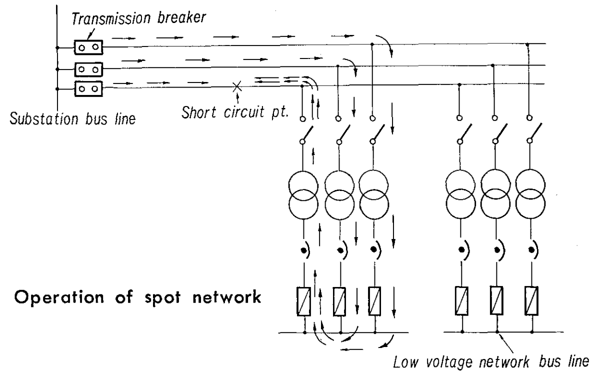


Fig. 2 Operation of spot network

networks were constructed only according to this characteristic.

2) In addition to this basic construction, low voltage supply systems with input on the low voltage side are also used to meet electric utility requirements in urban power distribution in the United States. It has therefore become desirable to be able to remote control the low voltage breaker on the user's side automatically from the utility's substation. Since it is very difficult to provide a control pilot wire from the substation to each user's low voltage breaker, a system was developed for remote control of the breaker without using a pilot wire. This is known as "an automatic secondary network." In such a system:

(1) Opening of the substation transmission breaker causes all the breakers of the transformers connected to the feeder concerned to open.
(2) Closing of the substation transmission breaker causes all of the low pressure breakers concerned to close automatically.

Therfore, the spot network has two additional characteristics, the exciting current breaking characteristic and closing characteristics.

IV. EQUIPMENT CONSTRUCTION

The greater the number of transformers connected in parallel, the greater the reliability, but the short circuit capacity on the low voltage side also increases. Improvement in the reliability and characteristics of the power distribution system are competitive with the short circuit capacity.

In the short circuit failure all low voltage short circuits are in principle handled by fuses. Because of this, the fuses play a major role and high reliability and correct operation are essential. Instead of the breaker on the high voltage side, a "network protector" is used on the low voltage side for low voltage network. The network protector usually consists of a low voltage breaker (ACB), a network relay and, when required, a network protector fuse.

It is sometimes possible to use a 30 kA network protector for the rated 50 kA breaker but in such cases, it is important that the ACB or quenching chamber and the arc space be small.

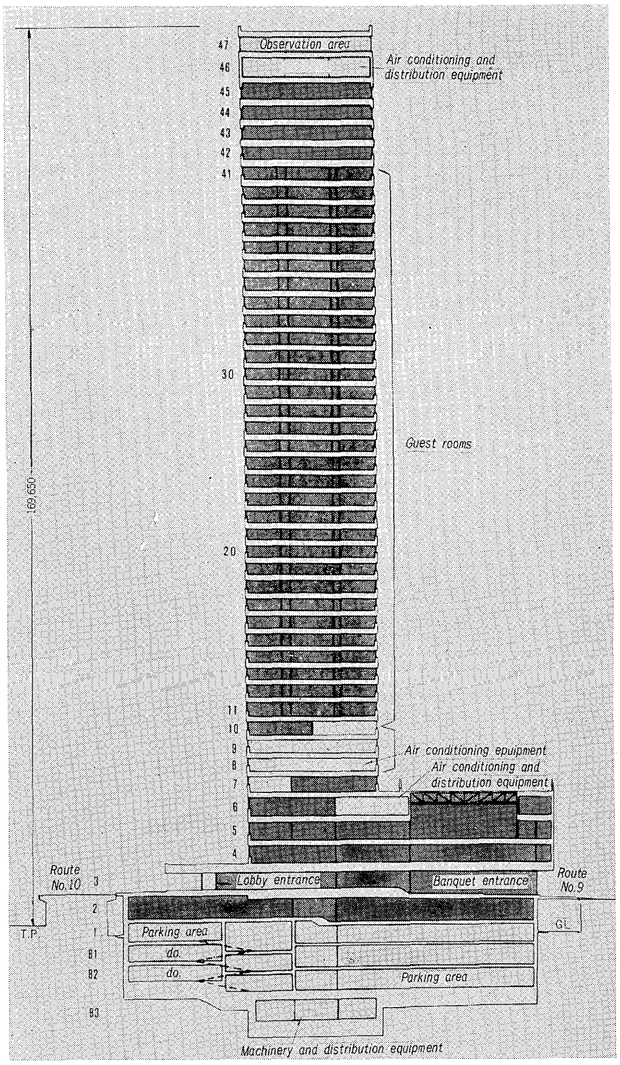


Fig. 3 Building section

V. OUTLINE AND FEATURES OF EQUIPMENT

Fig. 3 shows the building section and *Fig. 4* is a skeleton diagram of this equipment. 20 kV in 3 circuits is supplied from the Shinjuku substation of the Tokyo Electric Power Co. A 415/ 240 V spot network is constructed on the low voltage side in 3 banks of 2,000 kVA. The network transformer has an exciting current of such a magnitude that operation of the network protector is not hindered even when the voltage is 90% of the rated value. The overload withstand capacity is 8 hours at 130% which permits a 130% overload in the two remaining banks when there is a fault in one of the supply lines. The transformer capacity is selected so that 8 hours of continuous operation at full load is possible and the bank capacity is 2,000 kVA.

Normal and emergency lines are separated in the Take Off Fuse (TOF) and normal emergency switch over is performed in the TOF. This switching is performed by the under voltage relay connected to the network bus line and if there should be a commercial power interruption, there is automatic

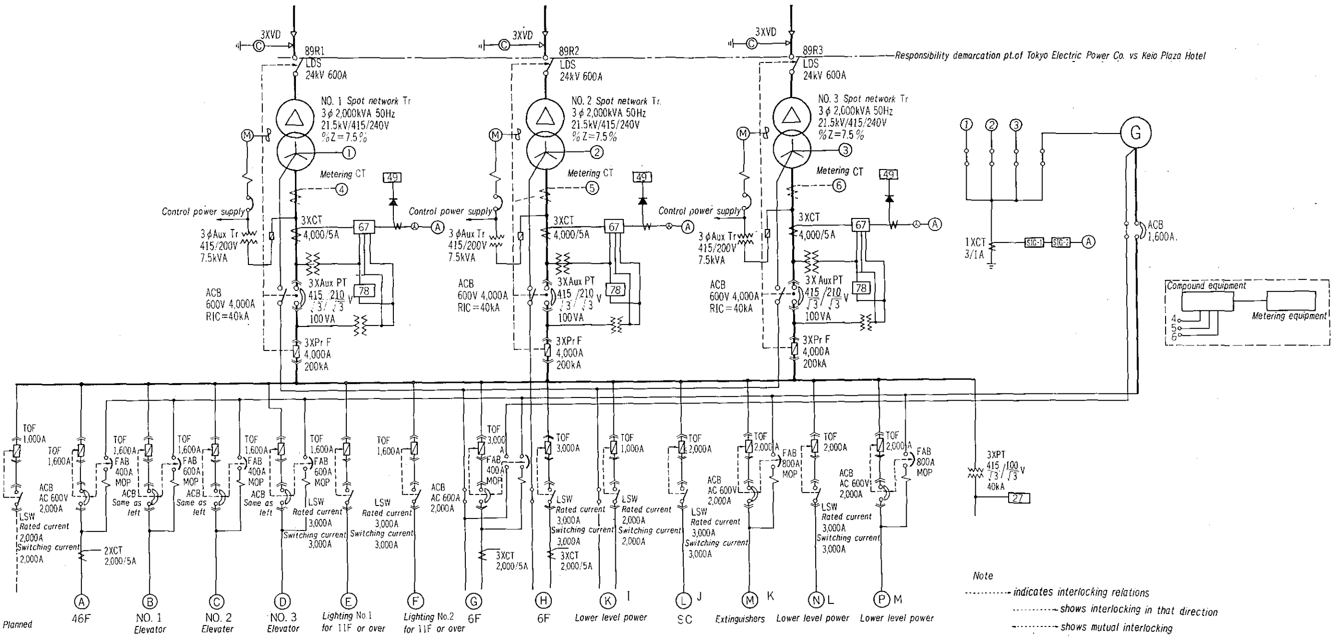


Fig. 4 Skeleton diagram

Table 1 **Application chart of Fuji Autobreaker back up by limiting fuse**

Current limiting fuse \ Autobreaker	B52/20	N63/15 N63M/15	N63/50 N63M/50	L100	L225	L400	L600 L800
AFC10-0	50kA						
FNH 100		50kA	80kA				
150			50kA				
200				130kA			
300					130kA		
400				100kA		130kA	
500							
600					100kA		150kA*
800							130kA
SH 500					200kA*		
1000							150kA*

Note 1) The current values are short circuit currents (asymmetrical effective values) which can be interrupted in the 460V circuit.
2) In the FAB types
B: breaker for lighting distribution panel
N: breaker with no current limiting
L: current limiting breaker and N□M/□ motor breaker with no current limiting
3) The above values were all confirmed in test runs except for these marked with * which were calculated.

Table 2 **Series breaking cooperation chart of TOF and low side fuses**

TOF (SH fuse) (A)	Low side fuse (Max. rating) (A)	Cooperation range (kA)
4000	SH 2000	~165
	SH 1600	~200
	FNH1000	~150
3000	SH 1000	~200
	FNH 800	~150
2000	SH 500	~200
	FNH 500	~150
1600	SH 500	~200
	FNH 300	~150

Series breaking cooperation of TOF and low side fuses

TOF (SH fuse) (A)	Low side breaker (Max. rating)	Cooperation range (kA)
4,000	L800	70
3,000	L800	70
2,000	L400	60
1,600	L225	50
1,000	N60	5
500	N30	2.5

switching from the normal to the emergency circuits. When the commercial power returns, the normal and emergency circuits are each operated independently and manual switching from emergency to normal must be performed for each feeder. The TOF circuit employs some load switch which can switch ther ated current in the normal circuits as an economy measure.

When selecting the TOF fuse, series breaking coorperation between the TOF fuse and the lower side FNH fuse or autobreaker is considered.

The TOF draw-out bus line is completely enclosed in an insulated bus duct so that there will be no ground faults or accidents, deliberate or otherwise, from the exterior. For ground current detection ground leakage relays with ground current detection sensitivities of 500 mA are attached to all the branch feeders below the TOF where it is very easy for ground foults to occur. These relays perform terminal selection detection. There is also a ground fault detection alarm for the whole system including the transformer secondary main which performs ground fault detection in the transformer neutral ground circuit. Ground fault detection in the neutral ground circuit is in two stages: the first for weak grounding of from 150 to 450 mA and the second for strong grounding of from 1.5 to 6 A. The magnitude of the ground fault is determined, the ground fault feeder is singled out and the maintenance man is informed quickly and clearly of the points where rapairs are needed.

VI. TRANSFORMERS AND DISTRIBUTION PANELS

1) Transformer panel

A load disconnection switch for switching the exciting current is located on the primary side of the transformers and operation of this switch is interlocked in such a way that it is possible only when the breaker on the secondary side of the transformer is open.

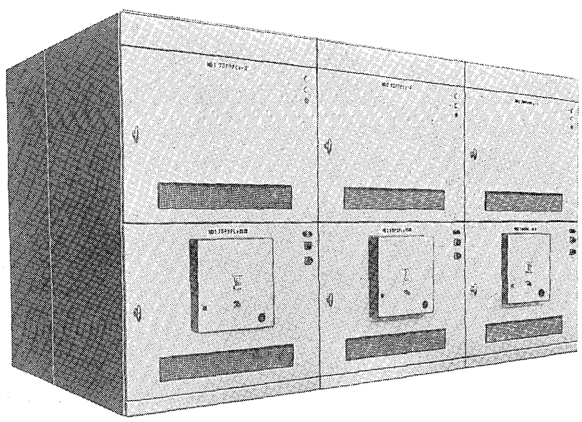


Fig. 5 (a) **Outer view of network protector panel**

2) Network protector

As was previously described for the breakers and fuses, interchangeability of each part and interlocking when pulled out has been considered so that attachment is very simple.

3) Take off panel

The front surface of this panel contains take off fuses, breakers and knife-type switches as well as private bus lines. As in the protector, interchangeability has been considered for the take off breakers, switches and fuses and the same construction is used for the pull-out devices, disconnection parts and interlocks.

4) Branch panel

The branch pannels are provided on the B3F (same location as receiving station), 6F and 43F. They are connected by bus ducts to the take off panels.

5) Network transformer

The network transformer has class H insulation and is of the forced cooled dry type which has proven so successful in the past. The cooling fan is normally operated when power is being applied to the transformer and simple operation is provided so that the fan will not start unnecessarily during overload operation.

VII. LOW VOLTAGE NETWORK COMPONENTS

In order to increase the reliability of the protector

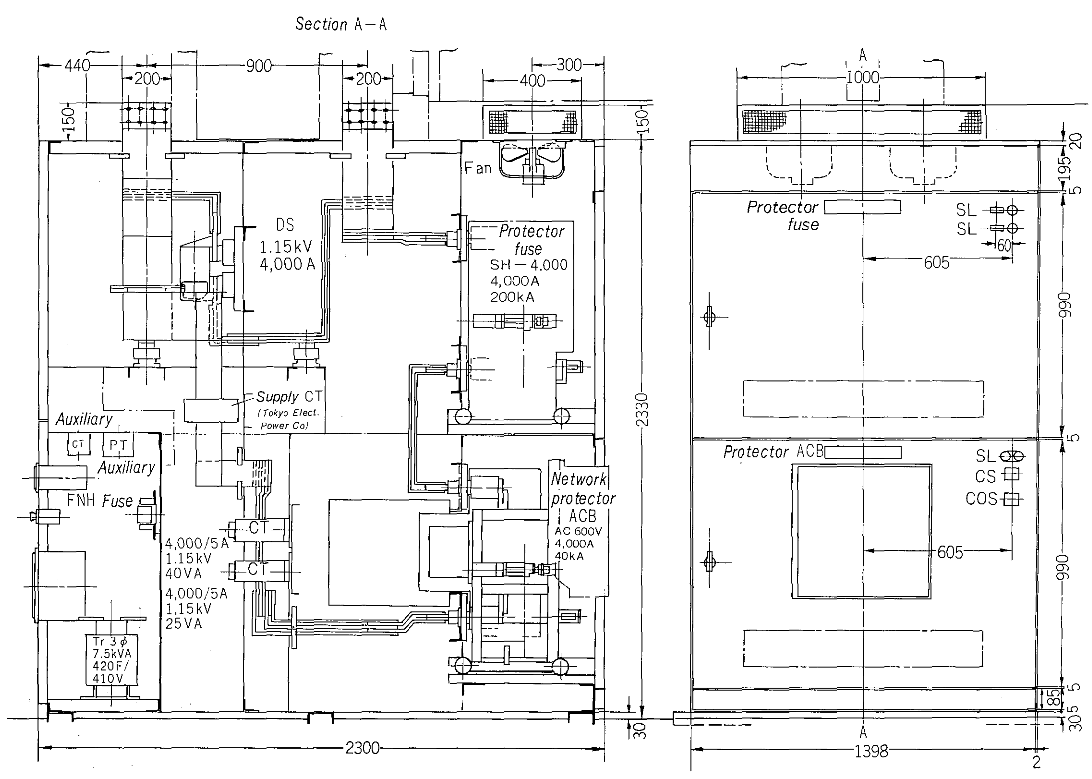


Fig. 5 (b) **Network protector panel**

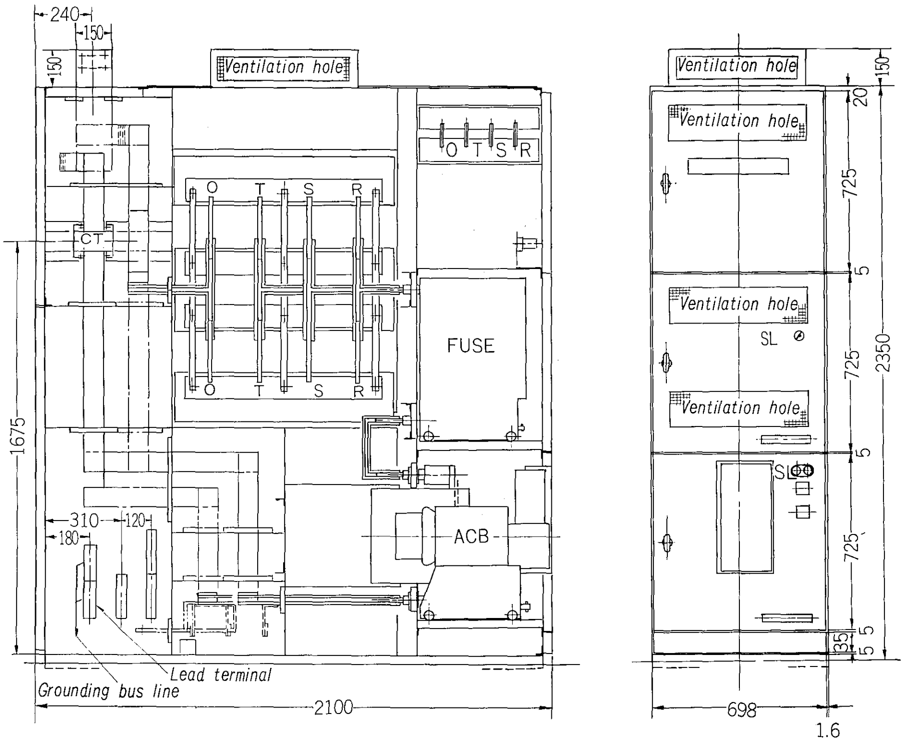


Fig. 6 (a) Take off panel

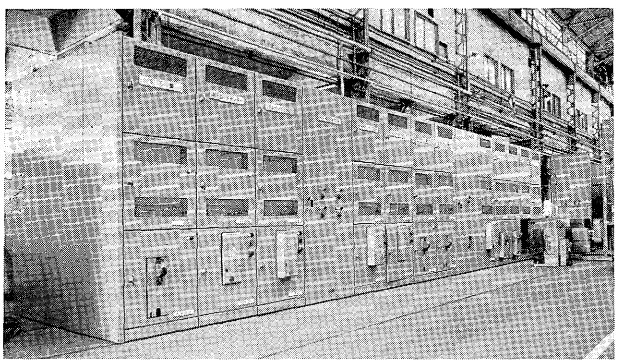


Fig. 6 (b) Outer view of take off panel

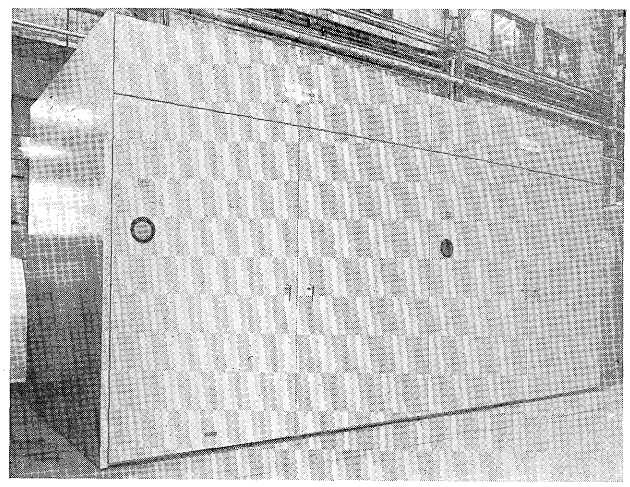


Fig. 7 (b) Outer view of main transformer cubicle

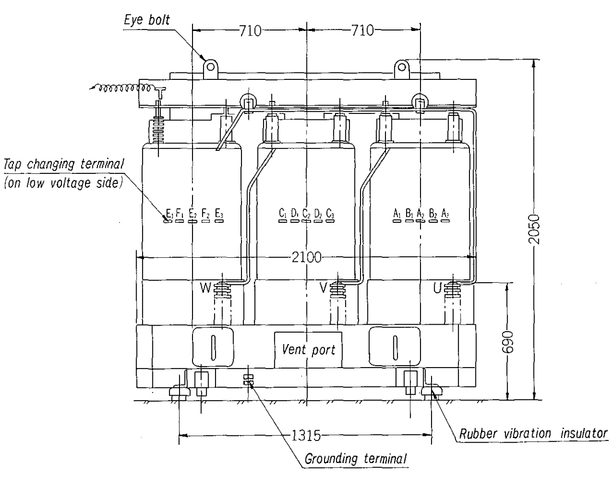


Fig. 7 (a) Main transformer

breakers and fuses and the insulation, an insulation barrier is arranged between the phases and ground. The protector fuses have a blow indication contact and make out-off-phase protection possible.

VIII. GENERAL CONSTRUCTION AND SHORT CIRCUIT CURRENTS

When the secondary main is considered to be correct, there is no limiter fuse, just as in regular networks. Therefore, when a short circuit occurs in this network secondary main, there is no limit as to the region and the protector fuses all blow one after another. By blowing all the protector fuses, the fault

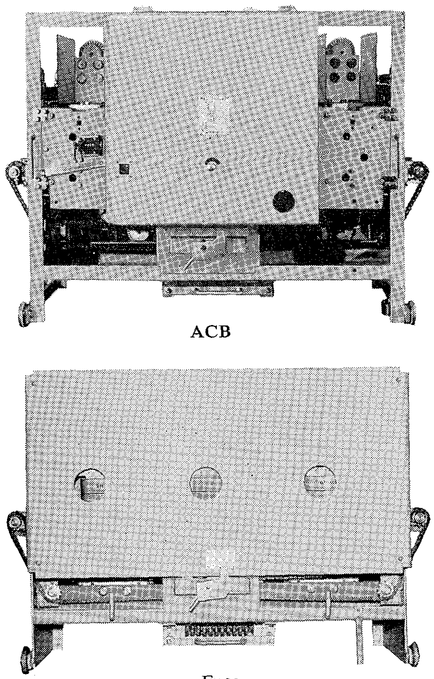


Fig. 8 ACB and fuse element for network protector

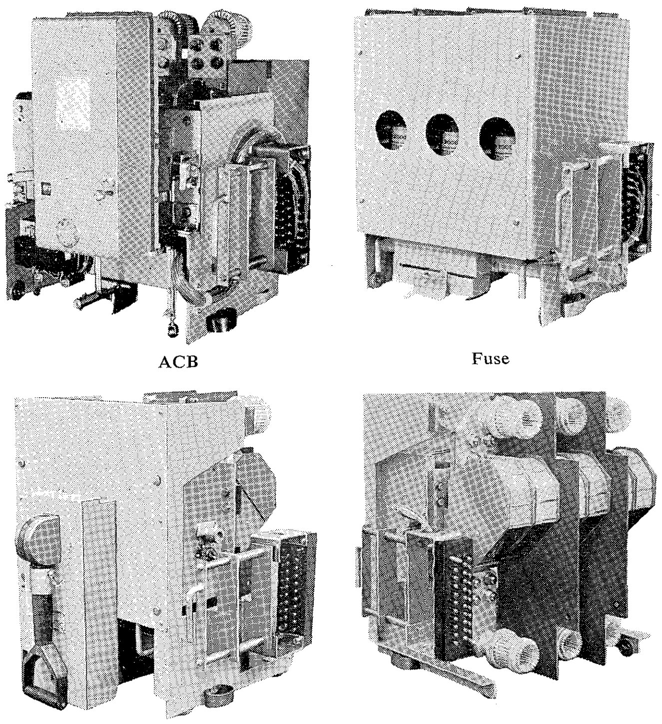


Fig. 9 ACB, LSW and fuse for TOF

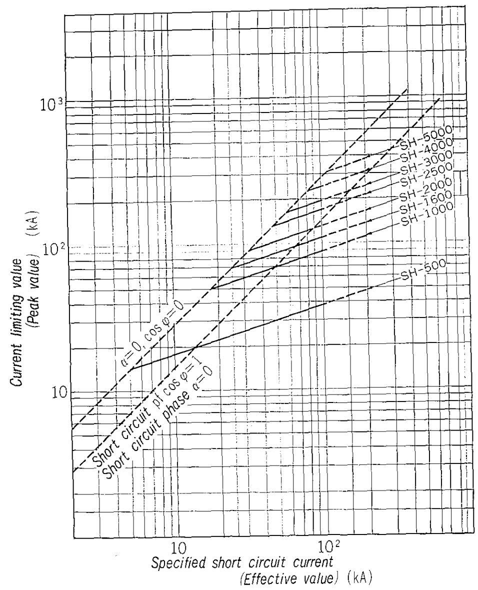


Fig. 10 Current limiting characters for protector and take off fuse (SH fuse)

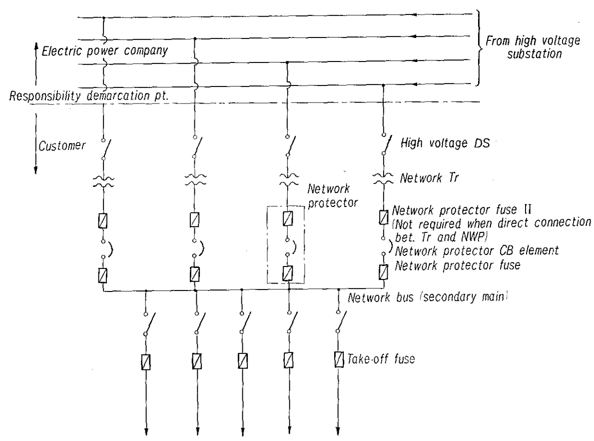
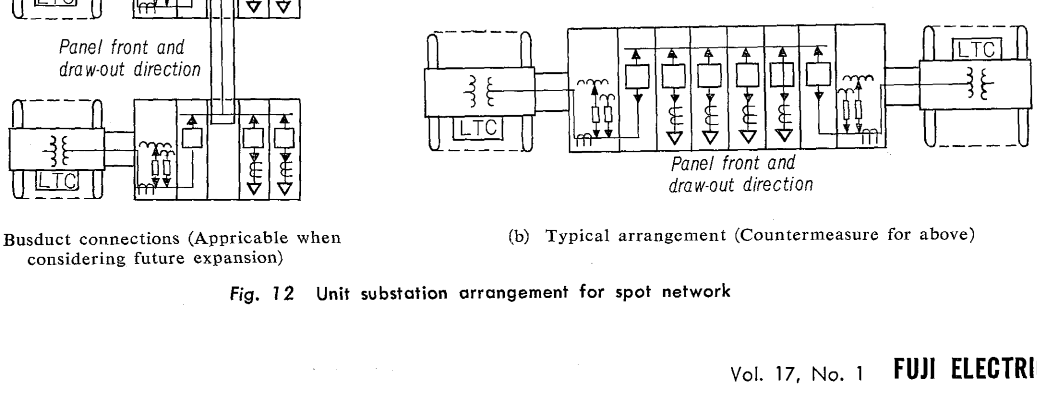


Fig. 11 Circuit fundamental arrangement



(a) Busduct connections (Appricable when considering future expansion)

(b) Typical arrangement (Countermeasure for above)

Fig. 12 Unit substation arrangement for spot network

Table 3 **Transformer characteristics**

Rated output (kVA)	Primrry voltage (kV)	Secondary voltage (V)	Z_T (%)	Connection	Type	Temperature rise (°C)	Exciting current (%)	Exciting current phase
500	23F-22F-21R-20F	240/415	5	△/人	Dry type or oil immersed	120 55	5	60°~90°
1,000	23F-22F-21R-20F	240/415	5	△/人	dO	120 55	3.5	60°~90°
1,500	23F-22F-21R-20F	240/415	7.5	△/人	dO	120 55	3.5	60°~90°
2,000	23F-22F-21R-20F	240/415	7.5	△/人	dO	120 55	3.5	60°~90°

Note 1. Overload operation at 130% of load for 8 hours after continuous operation at 100% load at ambient temperature of 30°C is possible.
2. There is a 3-phase 4-wire system on the low voltage side.
3. The transformer impedances Z_T should have as few mutual differences as possible since the network circulating current is small. However, even with the JEC manufacturing tolerance of ±10%, there is no particular hindrance when the system network relay is operated (NEMA No. TR-1957 is taken from ASA and there is a tolerance of ±7.5%).
4. The minimum value of the network relay operating current can be regulated from 0.2 to 3.0% (1.0 p.f.) in NEMA No. SG3.1 but this is not necessary in transformers with small iron loss which meet relay sensitivity.
A transformer economically meeting system requirements is sufficient.

Table 4 **An example of spot network receiving substation**

Total demand (Max.)	Rated transformer output (p.u.)	No. of units	Rated transformer current	Tr-Pro Bus line current capacity	Short circuit capacity	Network bus line current capacity	Short circuit capacity
(650 kVA) 500 kVA	500 kVA	2	695 A (904 A)	1,000 A	15,500 A	4,000 A	31,000 A
(1,300 kVA) 1,000 kVA	1,000 kVA	2	1,390 A (1,807 A)	2,000 A	31,000 A	6,000 A	62,000 A
(1,950 kVA) 1,500 kVA	1,500 kVA	2	2,065 A (2,710 A)	3,000 A	31,000 A	6,000 A	62,000 A
(2,600 kVA) 2,000 kVA	1,000 kVA	3	1,390 A (1,807 A)	2,000 A	62,000 A	6,000 A	93,000 A
(2,000 kVA)	(2,000 kVA)	(2)	(2,780 A (3,160 A))	(4,000 A)	(41,200 A)	(6,000 A)	(82,400 A)
(3,900 kVA) 3,000 kVA	1,500 kVA	3	2,065 A (2,710 A)	3,000 A	62,000 A	6,000 A	93,000 A
(5,200 kVA) 4,000 kVA	2,000 kVA	3	2,780 A (3,610 A)	4,000 A	82,400 A	6,000 A	124,000 A
(7,800 kVA) 6,000 kVA	2,000 kVA	4	2,780 A (3,610 A)	4,000 A	124,000 A	6,000 A	165,000 A

1. Transformer impedance is standard at 5% for 500 to 1,000 kVA (with JEC tolerance—refer to NEMA No. TR 4-1957) and 7.5% for 1,500 to 2,000 kVA (with JEC tolerance). However, small changes can be expected in practice from the planned values.
2. The rated tap voltage is as per JEC on the primary side and a standard 240 V/415 V 50 Hz 3-phase 4-wire system on the secondary side.
3. The temperature rise under rated conditions is as per JEC.
4. The transformer is either the dry or oil immersed type.
5. Impulse voltage is also as per JEC.
6. The above short circuit capacities are AC component effective values when the effects of the current limiting fuse are not considered.

Note 1. * Means not standard.
2. Values in parenthesis ( ) are with overloads considered.

point is removed from the network.

There is one other case when the equipment stops completely. This is the case when a sharp unbalance occurs in the power system considering the power network as a whole and the power station system and load system are separate, i.e. when there is a fault either on the power company's side or in the factory generation system.

Table 5 **Network protector arrangement**

No.	Network component	Network protector				Take off fuse	*1	*2
		ACB rating	ACB breaking capacity	Protector fuse rating	Protector fuse breaking capacity	Breaking capacity	ABC IB	Short circuit limiting value
1	500 kVA×2	1,000 A	20 kA (20 kA)	1,600 A	100 kA	100 kA	7.75 kA	12 kA
2	1,000 kVA×2	2,000 A	40 kA (35 kA)	3,000 A	100 kA	100 kA	15.45 kA	27 kA
3	1,500 kVA×2	3,000 A	50 kA (45 kA)	4,000 A	100 kA	100 kA	15.3 kA	32 kA
4	1,000 kVA×3	2,000 A	40 kA (35 kA)	3,000 A	100 kA	100 kA	20.6 kA	32 kA
5	(2,000 kVA×2)							
6	1,500 kVA×3	3,000 A	50 kA (45 kA)	4,000 A	100 kA	100 kA	20.45 kA	40 kA
7	2,000 kVA×3	4,000 A	70 kA	5,000 A	100 kA	100 kA	27.5 kA	50 kA
8	2,000 kVA×4	4,000 A	70 kA	5,000 A	200 kA	200 kA	30.9 kA	65 kA

Note 1. Values for ACB breaking capacity in parenthesis are specified values when 277/480 V of NEMA SG3.1 is used.
2. ACB short-time current values are the same as breaking current values and are for 1 sec.
3. *1 Actual breaking current when ACB interrupts.
This is for the case when a short circuit arises on the primary side of the transformer and it is equivalent to low voltage side short circuit current coming from the transformer of another feeder.
Transformer impedance Z_T has a JEC tolerance of 5% for 500 to 1,000 kVA and 7.5% for 1,500 to 2,000 kVA.
A limitless power supply capacity is assumed.
4. *2 Current limiting value due to protector fuse when a short circuit arises between the transformer and the network protector.
This specifies the ACB short time current. Peak values are shown.

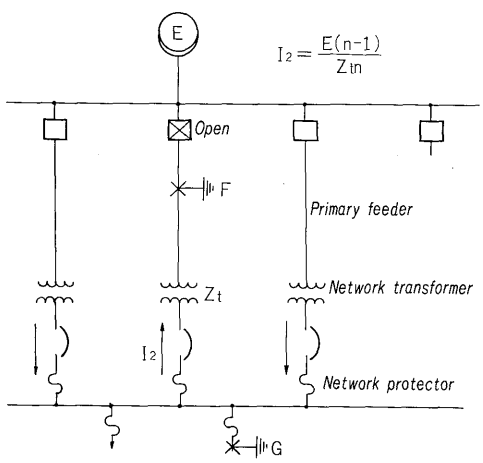


Fig. 13 **Fundamental form of failure calculation**

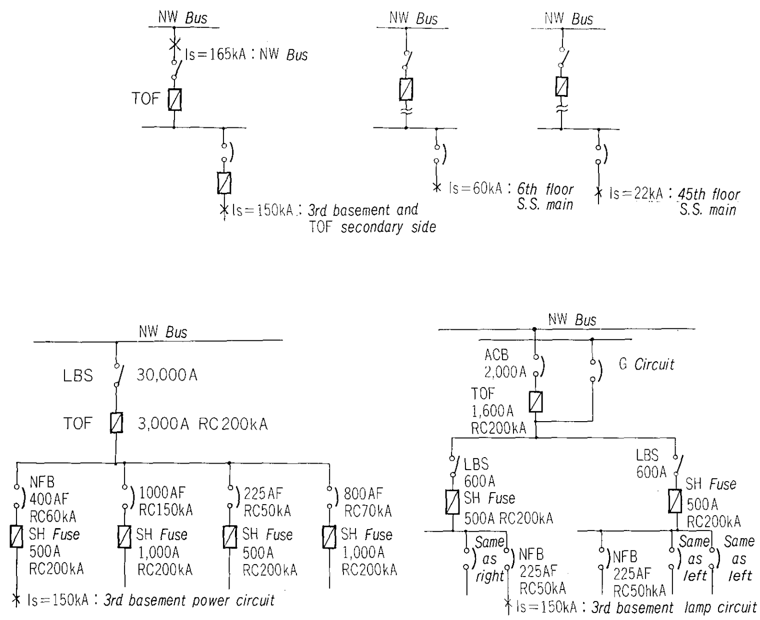


Fig. 14 **An example of LT feeders short circuit current**

The spot network is a highly reliable supply system but it is essential to consider measures so that there will be absolutely no faults in the network main.

Now the calculation of the short circuit current will be considered. The fundamental form of failure current calculation for the spot network system is as shown in *Fig. 13* and an example of LT feeders short circuit current in *Fig. 14*. Assuming that a short circuit occurs in the cable on the high voltage side, the following equation can be written when the impedances of the network transformers are $Z_T(\%)$ and $Z_{t(\text{p.u.})}$ and the rated voltage on the low voltage side are E_L(V) and $E_{l(\text{p.u.})}$:

If $E_{l(\text{p.u.})}=100$,

$$Z_{t(\text{p.u.})}=Z_T\times E\,(\text{p.u.})$$

$$I_{2(\text{p.u.})}=\frac{E(\text{p.u.})}{Z(\text{p.u.})}=\frac{E\,(n-1)}{Z_{tn}}(\text{p.u.})$$

Where n is the number of transformer units.

In this way, when the maximum breaking current

I_2 at which the network protector concerned must break when there is a short circuit on the high voltage side of the network transformer is calculated for an infinte impedance on the power line side, and the transformer manufacturing tolerances are considered separately, the results for a standard 415 V are as shown in *Table 6*.

When there is a ground short circuit for example, the total of the short circuit currents arising in each transformer is concentrated at one short circuit point. This can be considered as an extension of the calculation method used previously.

Additional points to be considered when planning include matters related to the elevator; changing the power related to the air conditioning to 415 V; changing over to the emergency power source; grounding the 415/240V system; cooperation between the ACB and the fuses, between the fuses and between the fuses and the load switch; the supply meters; voltages induced in the high voltage side of the network transformers by small exciting currents from the low voltage side; the possibility of attaching a fuse on the power supply side of the low voltage *PT*; the alarm system when the control power supply is interrupted; confirming the voltage on the secondary side of the 400V system transformer; checking the voltage on the 400 V network main; whether or not to include a closing lock for confirmation or employ automatic or manual ACB elements in the network protector; various types of interlocks; grounding of the feeders on the high voltage side of the network transformers; detection of 400 V system ground currents; and many more. All of these points must be decided so as to make the equipment as simple as possible.

Table 6 **Short circuit current in primary short failure**

No. of trans-former	$Z_T=5\%$			$Z_T=7.5\%$		
	I_2 (pu)	500 kVA	1,000 kVA	I_2 (pu)	1,500 kVA	2,000 kVA
2	10	6,950 A	13,900 A	6.95	13,900 A	18,500 A
3	13.33	—	18,550 A	8.9	18,600 A	24,800 A
4	15.0	—	—	10	—	27,800 A

IX. CONCLUSION

This article has described the main points to be considered when planning up-to-date spot network type receiving equipment. In the case of techniques and equipment related to underground power distribution, progress in the development of components considering the final overall construction is reducing wastefulness. The distribution lines are underground and it is difficult to move the equipment. There are many points concerning equipment construction which must be considered in terms of economy.

As was mentioned previously, this spot network can not only be used all over the country but also is applicable for spot loads in areas with high load densities. The regular network is being considered for underground distribution in respect to general loads other than spot loads.