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MODERN POWER SYSTEM ARRANGEMENT IN BUILDINGS

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I. INTRODUCTION

System planning and circuit arrangement for building power systems are a very wide field which covers many points. This article will be concerned solely with recent trends and problems in respect to modernization. As the number of buildings increase all over the world, they become larger in size, and also in height. Other major factors prevalent in modern buildings are beauty, safety, and a reliable power supply.

Since the operation of modern equipment tends toward the employment of as few people as possible, equipment must be simplified and automated using personnel only for maintenance and upkeep. (In response to these requirements, the rationalization of electrical equipment by means of high voltage/low voltage power distribution voltage such as 400 v power distribution, etc. is being attempted.) Recent trends are towards greater supply of power than previously using electrical equipment made smaller by means of size reductions and rationalization.

Fig. 1 New office building with Tokyo Tower in the background

II. SPECIAL POINTS AND PROBLEMS CONCERNING ELECTRICAL EQUIPMENT IN BUILDINGS

Because of the use to which it is put, electrical equipment in buildings is a very important part of the building facilities. However, although other building equipment has been modernized, electrical equipment is often not given much consideration in the overall planning, and equipment is poor, and reliability therefore is low. Electrical equipment is often placed in the corners of narrow partitioned areas or in inconvenient places which are of no other use in the building. The installation sites vary widely; sometimes the equipment is placed in basement areas and sometimes incoming transformer equipment, etc. is installed on the roof.

Various designs are possible, depending on the actual building. Therefore, it is essential to plan for safety and rationalization by collectively and systematically coordinating the characteristics of the electrical equipment with many other variables.

At the present time, many things have been electrified and it is no exaggeration to say that all of the facilities in buildings can be completely paralyzed during a power failure. Thus, it is not only absolutely essential to select a highly reliable system for incoming power distribution, but it is also necessary to select and rationalize highly reliable equipment so that power failures will not occur because of accidents in the equipment. In other words, operation should be automated wherever possible and the systems used should be such that all personnel time is concentrated on normal maintenance inspections.

The standard position for each piece of equipment is determined mainly from the viewpoint of safety according to the regulations concerned. Naturally, these must be fulfilled but, if the size and distribution of rooms are arranged in the buildings construction plans so that daily routine maintenance inspections as well as maintenance inspections during accidents can be carried out in complete safety, subsequent operation control will be sufficient. This in turn is essential in insuring power supply reliability.

City power companies and factory power distribution systems which transmit power to the building site, are tending to gradually change to underground

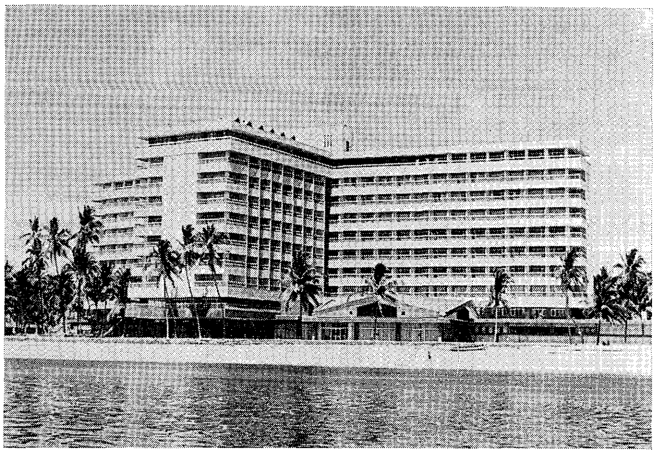


Fig. 2 Hotel

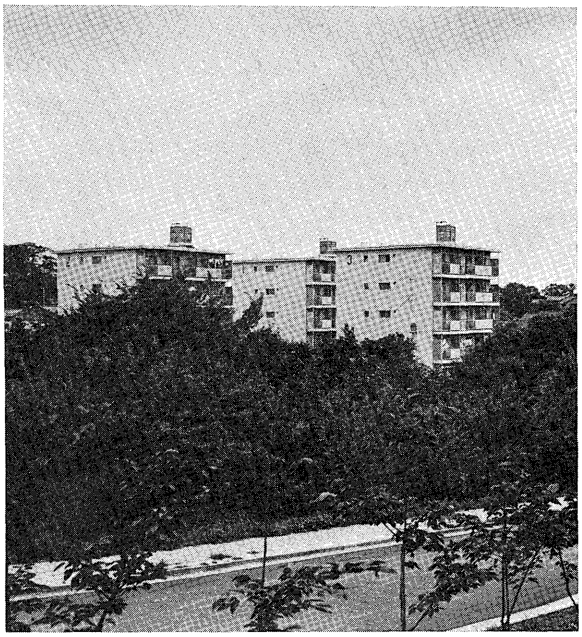


Fig. 3 Apartment building

power distribution as the area load density increases considerable. Since the initial capital investment is more than the overhead system, changing to the underground system is not carried out at one time but it is advisable to give sufficient consideration to the distribution and positioning of incoming transformer equipment in places where there is a possibility of such changes in the future. As the power load density tends to increase in built-up metropolitan areas, the distribution voltage also tends to increase in these areas. It is advisable to bear these points in mind.

Generally high voltage are better for the electrical charcteristics of the source side, i.e. the supply reliability and the voltage holding characteristics. In areas with underground power distribution, this new type of distribution has some influence on design of the incoming power distribution equipment in buildings which is not found with the overhead system. This is because, the percentage of accidents is less in very distribution lines which have been placed beneath the ground in cities or factory areas, but if there is only one circuit, time is required for re covery in the rare event that an accident should occur in the cable.

When planning the construction of electrical equipment for use in buildings, it is necessary to think about overall rationalization and economy by thoroughly investigating external conditions.

In modern buildings after the war, designs have tended to feature effective area configurations which can be universally applied. In other words, room partitioning is such that it can be changed to meet any requirements. Fixed room divisions are no longer employed like in previous buildings. Therefore, electrical equipment for use in buildings must be as adaptable as possible to changes.

Problems also arise in the construction of electrical equipment for buildings. In buildings up to 20 floors above the ground, steel reinforced concrete construction can be used as previously, but for buildings higher than this, the construction must be lightweight

Table 1 **Maximum Contracted Power and Standard Voltage to be Supplied**

Supplier * / Contracted Power	A	B	C	D
Less than 1000 kw	—	—	3.3 kv or 6.6 kv	—
More than 1000 kw	—	—	More than 11 kv	—
Less than 2000 kw	6.6 kv	6.6 kv	—	6.6 kv
Less than 10,000kw	11 kv or 22 kv	11 kv or 22 kv	—	11.22 kv or 33 kv
More than 10,000kw	66 kv	77 kv	—	66 kv

* Power Co.

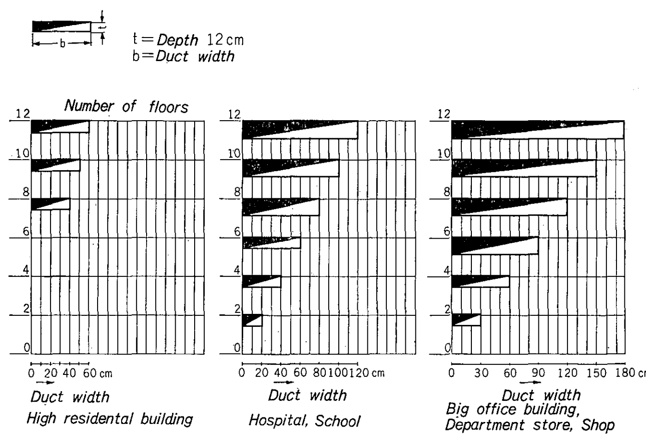


Fig. 4 Required dimensions for electric conductor penetration section or duct

to provide resistance against earthquakes. In order to provide flexibility, the so-called " flexible light-weight construction " is used. For this reason, slab driven piping cannot be employed as before, the distance between floors is not so large, and lines for weaker electricity such as lighting increase in number and become thicker. The curtain wall system is generally employed for the outside wall and room partitioning has become lightweight.

Buildings can be broadly classified as " office buildings ", " store buildings ", " department stores ", " residences ", " hospitals ", " schools ", etc. When distinguishing between high and low buildings, the application of electrical equipment is also governed by the above mentioned points. However, there is substantively not the wide variety of electrical equipment for buildings like there is for factories.

III. DETERMINATION OF THE INCOMING POWER SYSTEM AND THE INCOMING CAPACITY

When examining incoming power system, it is essential to consider the individual characteristics of the building in question. In a building there is not sufficient allowance for the floor area and ceiling hight like in a factory, and therefore a load center type switch-gear must not be installed optionally near the load center. Since there are many buildings in the central part of a city, the price of land has a great influence and, for reasons of economy, all large capacity transformer equipment is usually installed below ground, unlike in most factories. However, as buildings become higher, it often becomes uneconomical to collect all transformer equipment together and in such cases, a load center is also installed on the roof or on one of the middle floors.

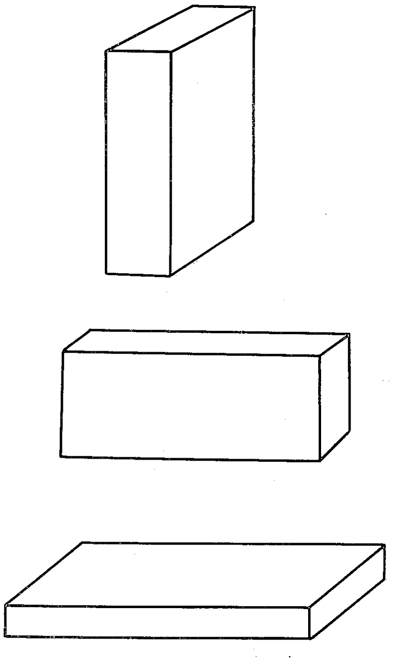


Fig. 5 Proportions of various building

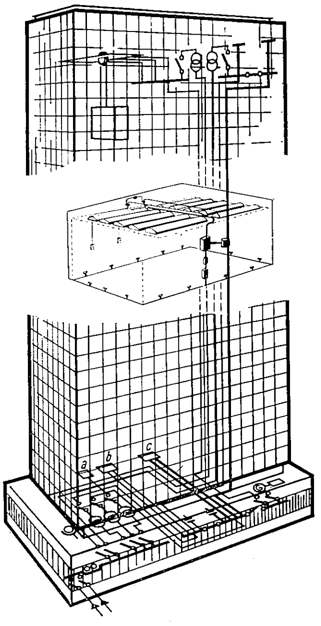


Fig. 6 General arrangement of electrical equipment in the building

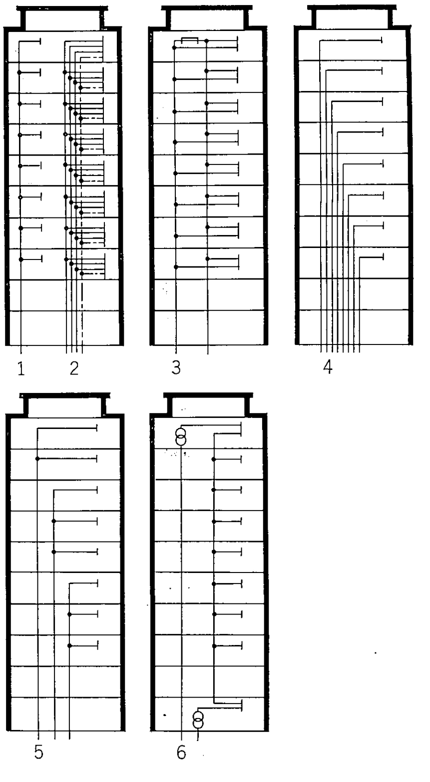


Fig. 7 Various examples of feeder risers and floor feeders

Generally, in such buildings, it is economical to limit the maximum length of feeders to below about 150 m. The main points are determined from economy investigations into the load center equipment cost and distribution system cost which are lowered by installing the load center as well as investigations into supply reliability according to the purpose for which the building is intended and technical investigations concerning miscellaneous voltage drop, etc.

There are many restrictions on the high voltage side of the incoming power system in accordance with the location of the building, i.e. the power distribution network in that area. Therefore when deciding on a system, previous arrangements must be made with the power company.

1. Determination of Incoming Power Capacity and Transformer Capacity

When determining the incoming power capacity of a building, it is first necessary to assume the load equipment capacities and from the total of these, the output of the transformer can be determined. However, from the time of the original design, the details of each piece of the load equipment are virtually unknown, and therefore transformer equipment already in use which resembles the proposed plan in application and scale is used as a reference for capacity computations, and future extensions are generally taken into consideration.

The load can be broadly classified as lighting load, power load, and cooling/heating load which is used only in summer/winter respectively. *Table 2* shows the average power required per unit area by the various loads for general office buildings, stores, department stores, hotels and residences.

Transformer capacity is generally determined by considering the demand factor, diversity factor, and load factor along with the load equipment total, but, apart from the demand factor, many problems

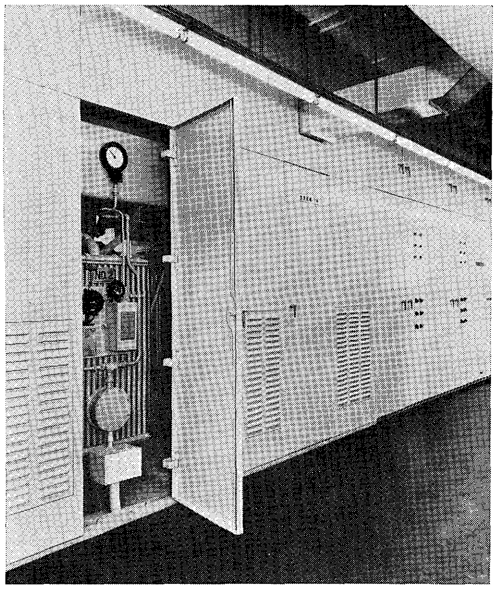


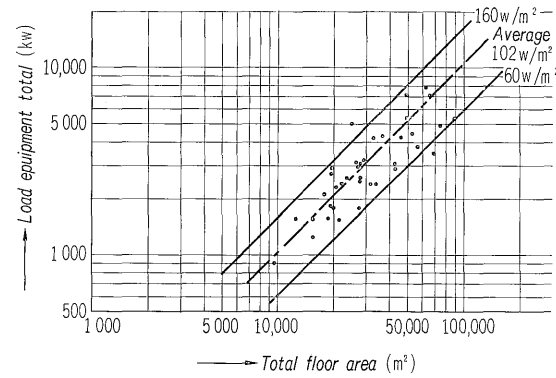
Fig. 8 Incoming power cubicle

***Table 2* Required Power for Building with High Voltage and Special High Voltage[1] Reception**

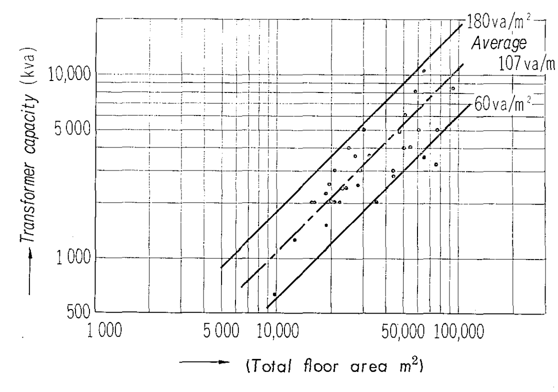
	General Office Building		Shop, Depertment Store	Hotel	Residence
	w/m²	Spec. H.V.[2] w/m²	w/m²	w/m²	w/m²
Lighting	25	25	35	30	20
Normal Power	30	38	30	40	21
Cooling System	38	39	40	30	30
Total	93	102	105	100	65

Data taken from investigations of the Japan Electrical Equipment Industry Association between 1964 and 1966

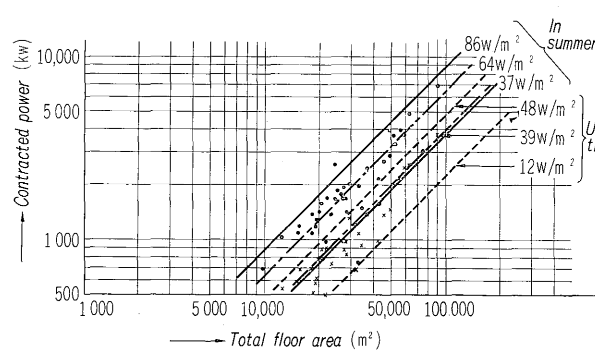
Note: (1) High voltage: Rated voltage 600 v~7 kv
Special high voltage: Rated voltage over 7 kv
(2) This data is from "Research into the technical Standards of large capacity power trunk lines in very high building" published by the Japan Electrical Equipment Industry Association



(a) Load equipment capacity vs. total floor area occupied



(b) Transformer capacity vs. total floor area occupied



(c) Contract power vs. total floor area occupied

Fig. 9 Power capacity installed and total area occupied exist with building equipment in actual practice when considering the diversity factor, etc.

If an actual case of a building is examined, it can be seen that there is a mutual relation between the load total and the transformer equipment capacity. In other words, the transformer capacity in respect to the transformer secondary load (kw) is as follows:

High voltage/special high voltage incoming power
60∼140% average value 95%

Special high voltage incoming power
70∼150% average value 105%

Calculation example

General office building (special high voltage incoming power)

With an area of 32,000 m²,

lighting load: $25\ w/m^2 \times 32{,}000\ m^2 = 800$ kw

general power load: $38\ w/m^2 \times 32{,}000\ m^2 = 1200$ kw

cooling system load: $39 w/m^2 \times 32{,}000\ m^2 = 1250$ kw

special high voltage incoming transformer capacity: $102\ w/m^2 \times 32{,}000\ m^2 \times 1.05 = 3420$ kva

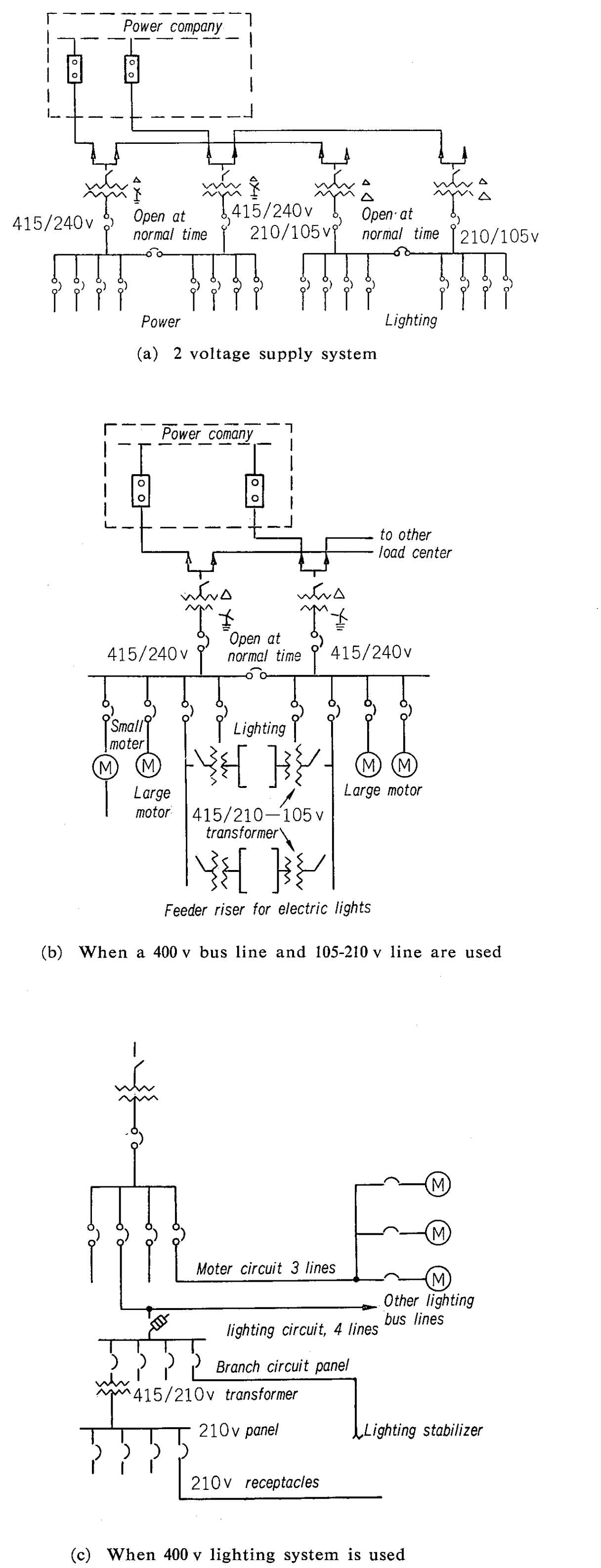
With reference to general office buildings constructed between 1961 and 1966, the following relations for buildings with special high voltage incoming power are shown in *Fig. 9*:

Load equipment capacity	vs. total floor area
Transformer capacity	vs. total floor area
Contructed power	vs. total floor area

IV. DETERMINATION OF DISTRIBUTION VOLTAGE AND DISTRIBUTION SYSTEMS

When planning distribution systems for the interior of buildings, the first problems which arise are whether to use 3 kv or 6 kv etc high voltage system or whether to use only the 400 v system. Although it depends on the power source capacity, there is no difficulty in direct starting of a 150 kw type 3-phase induction motor with a 400 v, 3-phase system. Generally, in electrical equipment for buildings, large capacity motors are mainly used for air conditioning and the amount of energy supplied from the electrical side will vary depending on whether or not an absorption system is employed in the air conditioning system.

In buildings, air conditioning power equipment is generally positioned near the main switching system and therefore there are many times when it is more advantageous for the entire system to select a low voltage whenever possible rather than a high voltage for the distribution voltage. In other words, it is sometimes better to employ 400 v than 6 kv or 3 kv. For lighting equipment, there are cases when it is more economical when considering the entire system to use 200 v instead of 400 v. Basically it is advisable to reduce and simplify the number of bus lines and distribution transformers by reducing all voltages anyway possible and also by using the 3-phase 4-line system, etc. When using 400 v distribution, 415/240 v at the transformer secondary in 50 Hz areas and 460/260 v in 60 Hz areas are recommended for 3-phase are 4-line systems in Japan.



(a) 2 voltage supply system

(b) When a 400 v bus line and 105-210 v line are used

(c) When 400 v lighting system is used

Fig. 10 Typical single line diagram for a commercial building

As was mentioned previously, there are many factors which govern the number of high voltage feeders for the interior of buildings. Therefore, it is usually

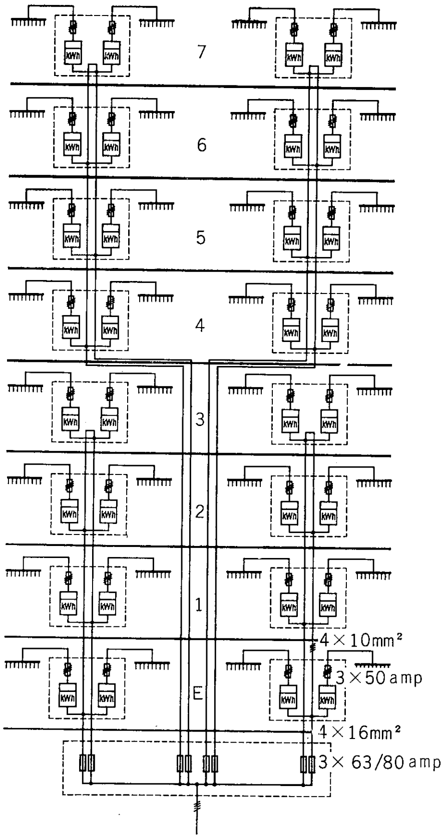


Fig. 11 Example of ring type feeder risers for residential building

Table 3 **Number of HV Feeders in HV and EHV Incoming Power**

Reception Transformer Capacity (Load capacity with usual voltage reception)	Number of HV Feeders (Including condenser feeder)
Less than 500 kva	2～4 feeders
500～1000 kva	3～5 feeders
1000～1500 kva	5～7 feeders
1500～2000 kva	7～10 feeders
2000～3000 kva	7～10 feeders
3000～4000 kva	8～11 feeders
4000～5000 kva	9～12 feeders
5000～6000 kva	10～13 feeders

not possible to select the correct number of feeders in respect to the incoming power constructed in Japan which have high voltage bus lines are as shown in the examples given in *Table 3*.

Considering the grounding systems for building incoming power systems, the GPT system is generally used for 6/3 kv systems with special high voltage incoming power; the non-grounded system for 6/3 kv systems with 6/3 kv incoming power, and the central point direct coupling grounding system for the 400 v

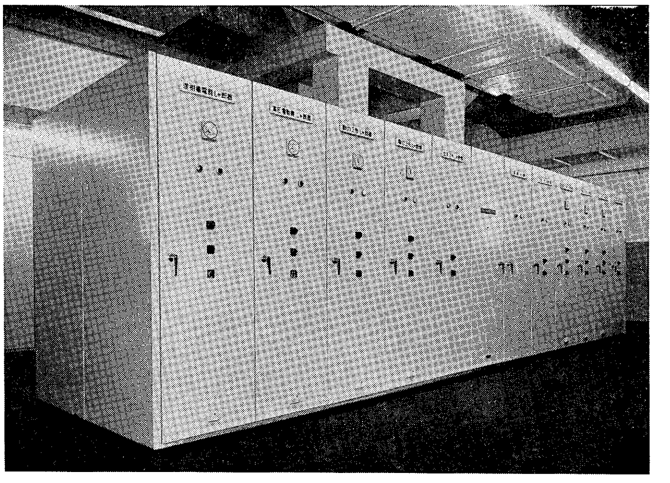


Fig. 12 High voltage cubicle

3-phase 4-line system. Grounding is carried out in respect to other voltages in accordance with technical standards* depending on transformer primary and secondary voltage values.

* N.B. In Japan, Technical Safety Standards are employed.

The 3-phase 4-line system with the central point direct coupling grounding system is used especially for 400 v distribution, but the central phase is not the grounded line; it is the electrical line and requires the same insulation as for other circuits. Fluorescent lamps and mercury discharge lamps generate many third harmonics and if central lines and equipment grounding lines are common, this will cause residual current to occur at the central point normally. When a small capacity step-down single-winding transformer is used for 100 v lighting, the 400 v and 100 v mutually influence each other since one end is grounded, etc. With direct coupling grounding, the required magnitude of zero phase voltage is not obtained during relay operation and therefore care must be taken when planning the grounding protection.

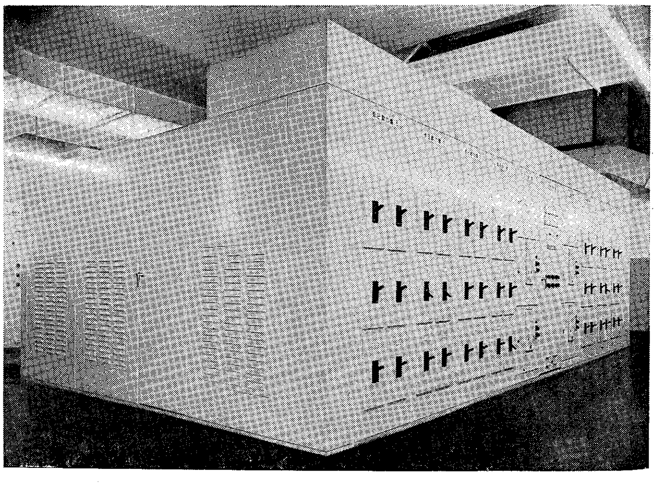


Fig. 13 Low voltage cubicle

V. SHORT CIRCUIT COMPUTATION AND PROTECTION SYSTEM

There is a slight difference in respect to the impedance elements of high voltage circuits and low voltage circuits when considering short circuit currents. In a low voltage system, the operation time of the circuit breaker is very rapid (1/2 cycle after the short circuit develops) and therefore, it is also necessary to consider the contribution of the induction motor to the capacity of the circuit breaker. The reduction effect of the short circuit current becomes large because of the cable and the impedance elements cannot be disregarded. In contrast to this, the circuit breaker operation time is 3 cycles in high voltage systems, and it will not interrupt short-circuits while in the transient state. The cable is also usually short and therefore, in respect to the same basic capacity, the higher the voltage, the lower the short circuit current reduction effect at the same impedance (ohm value). Therefore, sufficient precision in the calculation of short-circuit capacity can be obtained from the transformer impedance alone.

Table 4 **Operation Characteristics of Circuit Breaker for 3/6 kv Reception**

Power Co.	O.C.Ry. Current Tap Setting Value	Operation Limit
A	1.5 times contracted power	200% 0.5 sec
B	1.5 times contracted power	150% 0.2 sec
C	1.5 times contracted power	150% 0.3 sec

It is possible to use fuses and circuit breakers for short circuit protection but when selecting these, the fundamental regulation "Automatic circuit breakers must have the capacities required by the installation site" from the technical standards must be followed. The selective breaking system, backup system (known as the cascade system especially at low voltages) etc. are used depending upon the permissible accident limits in respect to hypothetical accident points; The level time limit system is generally used to coordinate the times of these systems.

The performance characteristics of the circuit breaker for incoming power are determined by consultation with the power company. The following values are required especially with 3/6 kv incoming power.

VI. POWER FACTOR IMPROVEMENT SYSTEM AND SUPERVISORY CONTROL

A condenser for phase advancing is generally used in buildings to improve the power factor, but when the condensers are positioned at various places throughout the building, it is difficult to detect accidents in the individual condensers, and when they are centralized together in one place, reactive current flows in branch circuits inside the building if the capacitors are positioned in a place near the power source terminal. Therefore, load distribution conditions determine whether the centralized system or the dispersion system is used.

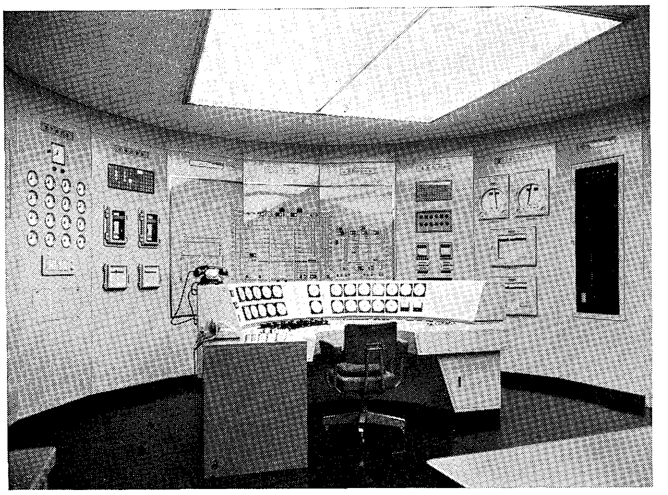


Fig. 14 Central incoming and control panel

Because of the large increases and greater distribution of load equipment in modern buildings, centralized supervisory control is becoming more common in order to effectively control the operating conditions of the entire system.

The number of control instruments on the panel has been reduced to the required minimum and the elements essential in daily recording are made with the type system by means of loggers or recorders so that the size of the panel has been decreased considerably. An example of the centralized supervisory control penel is shown in *Fig. 14*.

VII. SELECTION AND DISTRIBUTION OF EQUIPMENT PARTS

1. Selection of Equipment Parts

The equipment used in buildings differs from that generally used in factories, etc. in that because of the fire hazard, it must be non-inflammable and contain fire extinguishers, and it must also be small in size. Other points concern economy, high reliability, and simplicity of maintenance and inspection. For the prevention of fire, local government office regulations (proclamations, controls, etc.) must be followed in respect to the construction material used for the buildings, etc.

In the Tokyo regulations (Fire prevention regulations), the following stipulations pertain to the application of fire extinguishing equipment with electrical machinery. (Refer to Table 5).

Table 5 Fire Extinguishing Equipment Standards for Electrical Machinery

Voltage	Power	Type of Electrical Equipment	Fire Extinguishing Equipment
Special High Voltage Incoming Power	—	Dry-type machine	Large-type fire extinguisher
	—	Machine with oil	Stationary-type fire extinguisher
Usual High Voltage Incoming Power	Less than 500 kw	Dry-type machine	Small-type fire extinguisher
		Machine with oil	Small-type fire extinguisher
	More than 500 kw	Dry-type machine	Large-type fire extinguisher
	Less than 1000 kw	Machine with oil	Large-type fire extinguisher
	More than 1000 kw	Dry-type machine	Large-type fire extinguisher
		Machine with oil	Stationary-type fire extinguisher

Note: 1) Small-type fire extinguisher: Standard manual portable type
Large-type fire extinguisher: Standard type with wheels attached
Stationary type fire extinguisher: Standard water atomizing, foam, non-inflammable gas, or powder type fire extinguishing equipment
2) The T-type circuit breaker (minimum oil circuit brerker) uses oil but the amount employed is so small that it can be considered the same as dry-type machines such as magnetic circuit breaker etc. in respect to fires

The most important equipment is determined by considering the special characteristics given above. It is essential to select products which well match these characteristics and are highly reliable.

2. The Required Areas and Distribution

The area required for incoming power transformer equipment can be considered as constant in respect to the equipment capacity in buildings used for the same purpose. Previously, the smallest possible area for a transformer substation was considered as proportional to the square root of the overall tranformer capacity,

Therefore:

required area (m^2) $= 3.3\times\sqrt{\text{total transformer capacity}}$

Actually, when a generator for emergency or a large capacity storage battery is required, additional floor space must be considered. However, from data gathered concerning equipment used in recently constructed buildings, it is different from these tendencies a little. The building voltage systems can be classified broadly as

1) Incoming power of 22 kv and 3 kv circuit (2000∼10,000 kw)
2) Incoming power of 22 kv and 400 v stepdown transformer (1000∼5000 kw)
3) 6.6 kv or 3.3 kv incoming power (50∼2000 kw)

In these three cases, the following approximate relations exist between the overall equipment capacity and the required floor space:

1) Required floor area (m^2) = 1.7 (overall equipment capacity kva)$^{0.7}$
2) Required floor area (m^2) = 1.4 (overall equipment capacity kva)$^{0.7}$
3) Required floor area (m^2) = 0.98 (overall equipment capacity kva)$^{0.7}$

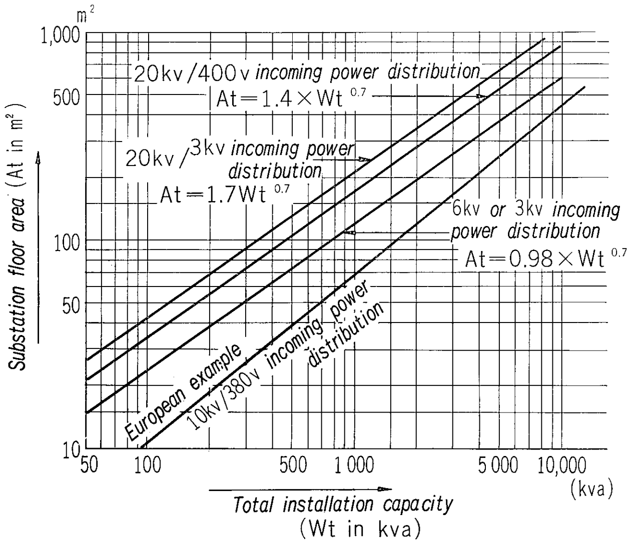


Fig. 15 Total installation capacity vs. substation floor aera

These relations are shown graphically in *Fig. 15*. With the same high voltage incoming power system, the equipment capacity becomes large and therefore the required floor space is greater than the previous space determined by the square root of the capacity. Plans for this large capacity transformer substation should allow for sufficient space for maintenance and inspection and the use of distribution panels and especially supervisory cantrol panels. When the capacity is small, distribution panels. etc. can be simplified and the front surface area of the distribution panel can be decreased considerably. The area can also be decreased further by employing the enclosed panel system, by using the compartment system and decreasing the size of the equipment. When a supervisory control room is used, the required floor space

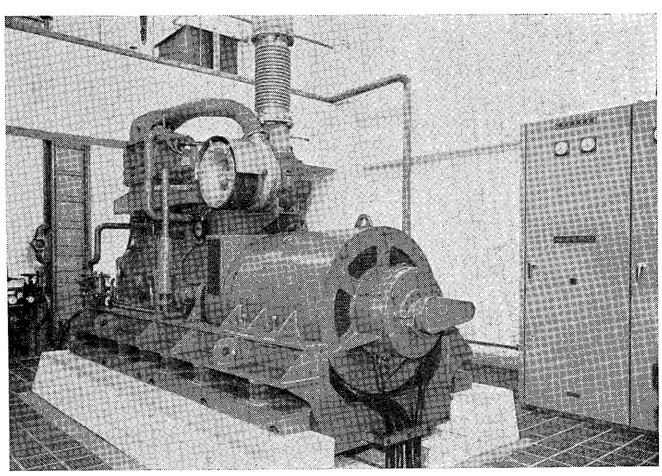


Fig. 16 Emergency diesel generating set

is only 25% of the above mentioned floor spaces.

Smaller problems also arise. The construction of the internal tranformer when 60 kv or 70 kv incoming power is employed and the transformer substation with 20 kv and 30 kv underground distribution system power reception (ex. network power reception) present many problems. However, official proclamations have been issued concerning these matters and Fuji Electric hav collected new material which will be announced at a later date.

With indoor transformer substations, there are patterns for power distribution when the compartment system, metal-clad switchgear series, loop power reception, or secondary network power reception is used. There is also some type of pattern for emergency source generator areas and storage battery areas. These matters will also be announced at a later date.

VIII. CONCLUSION

This article contains results of investigations and many problems concerning planning for the construction of basic electrical equipment for actual use in buildings constructed recently. It is considered that building electrical equipment must be faster and more simplified than before, and therefore efforts must be made to produce equipment adapted to these requirements.

The features of the metal clad switchgear series widely used previously in electrical equipment for buildings are : it is easy to construct a unit system transformer substation when the equipment has been installed at the site for only a short time, high reliability equipment construction is possible and the external appearance is good. However, the unit substation must be installed after a very short installation time which is limited by the complex equipment distribution and therefore in buildings this is generally not so prevalent as with heating power plans. The equipment also must not be installed in places where there is a lot of dirt present and for this reason, there are many examples of the use of the so-called compartment system for installation of electrical equipment in buildings. Since the details of the metal clad system are widely known, it was not described extensively here. A unique type of concstruction can be expected with electrical equipment employing the T-type circuit breaker minimum oil circuit breaker.

Future buildings will become larger, the number of feeders required for operation will increase and control will become complete and automatic, requiring less personnel. When this occurs, the metal clad switchgear system which means high system reliability and uses the unit and pull-out systems for the electrical equipment, will become indispensable. The so-called metal-clad system, load center system and control center system will be developed to the optimum.

Therefore, it is hoped that these components will be utilized in accordance with the individual characteristics of each building. Please use Fuji Electric's power distribution equipment and general equipment. The author hopes that this article will serve as a useful reference for planning such equipment.