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POWER RECEIVING SUBSTATIONS FOR WATER AND SEWAGE WORKS

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I. INTRODUCTION

The position occupied by power receiving substations in water and sewage works is the same as that occupied by those in ordinary industrial plants, i.e. they act as sources of drive power for various machines of the works such as the treatment plants and sewage treatment plants. However, in accordance with the special characteristics of public utility plants, the shut-down of the every facilities by momentary power failure is not permissible because there must be reliable water transport and distribution in water works and complete treatment of both household and industrial waste water in sewage works.

Therefore, system reliability is the major requirement for electrical equipment in all systems including the electric receiving, distribution and plants control systems. This article describes the concepts used in the construction of electrical equipment designed under the above conditions and introduces examples of such equipment supplied by Fuji Electric.

II. SUPER HIGH VOLTAGE RECEIVING EQUIPMENTS

The scale and level of water and sewage works are increasing every year and as a result, the receiving voltage are rising from ordinary to super high voltage. *Table 1* shows the relation between receiving voltage and power capacity. There are cases when 60 kV is supplied because of the conditions of the power company distribution networks if the plant scale is over 2,000 kW.

Table 1 **List of receiving voltage and power capacity**

Receiving voltage	Standard receiving power capacity
200 V	under 50 kW
6 kV (3) kV	50 kW less than 2,000 kW
20, 30 kV	2,000 kW less than 10,000 kW
60 kV, 70 kV	10,000 kW less than 50,000 kW
140 kV	50,000 kW and over

Table 2 **Installations in sewage works**

Load name	Capacity (kW)	No.
Dirty water inlet gate	2.2	3
Rainwater inlet gate	3.7	3
Discharge gate	5.5	1
Bypass discharge gate	5.5	1
Large-mesh screen	1.5	6
Sediment collecting device	2.2	3
Grab-type sand elevator	26.85	1
Flight conveyer	7.5	1
Small-mesh screen	3.7	6
Belt conveyer	3.7	1
Screen sediment grinder	19	21
500ϕ sewage water pump	75	3
800ϕ sewage water pump	150	2
500ϕ motor valve	1.5	3
800ϕ motor valve	2.2	2
1,000ϕ rainwater pump starting panel	—	1
1,100ϕ motor valve	2.2	3
Water supply pump	1.5	3
Air compresser	3.7	2
Lubricating oil pump	0.75	3
Well water pump	3.7	3
Fuel oil pump	0.75	1
Overhead travelling crane	5.5	1
Power supplies for various solenoids	—	1
Power supplies to operate starters	—	1
Blower	240	3
300ϕ motor valve	0.4	3
Lubricating oil pump	3.7	2

Load name	Capacity (kW)	No.
Overhead travelling crane	7.7	1
Initial sediment collecting device	1.5	4
Initial sediment horizontal collecting device	0.75	2
Activated sludge transport pump	18	2
Activated sludge transport pump motor valve	0.4	2
Motor valve for removal of initial sediment	0.4	2
Sediment discharge gate	2.2	1
Aeration inlet gate	3.7	1
Skimmer	0.2	12
Scum seperator	0.4	1
Activated sludge transport piping washing pump	11	1
Activated sludge transport piping washing pump motor valve	0.4	1
Treated water discharge pump motor valve	1.5	1
Drainage pump	7.5	1
Final sediment collecting device	1.5	12
Final sediment horizontal collecting device	0.75	3
Return sludge pump	15	3
Return sludge pump motor valve	0.4	3
Excess sludge pump	5.5	2
Excess sludge pump motor valve	0.4	2
Return sludge flow control valve	0.75	1
Froth spray pump	15	1

The characteristics required of power receiving substations in water and sewage works are as follows:

1) Equipment and system reliability must be high.
2) There must be a stable supply of power to a large number of loads scattered over a wide area.
3) The systems and component equipment must be flexible to permit easy expansions in the facilities.
4) The equipment must not corrode under severe environments such as in the case of sewage treatment.
5) Low noise equipment must be used in facilities located in cities or surrounding areas.
6) The frequency of maintenance and inspection must be low and such operations must be easy.

With the exception of super high voltage receiving equipments, these requirements are necessary for all of the equipments described in the following sections. *Table 2* gives an example of the load equipment required in a sewage works for the distribution of power from a super high voltage substation.

1. Super High Voltage Receiving Systems

Skeletons of the receiving systems are shown in *Fig. 1* and they are compared in *Table 3*.

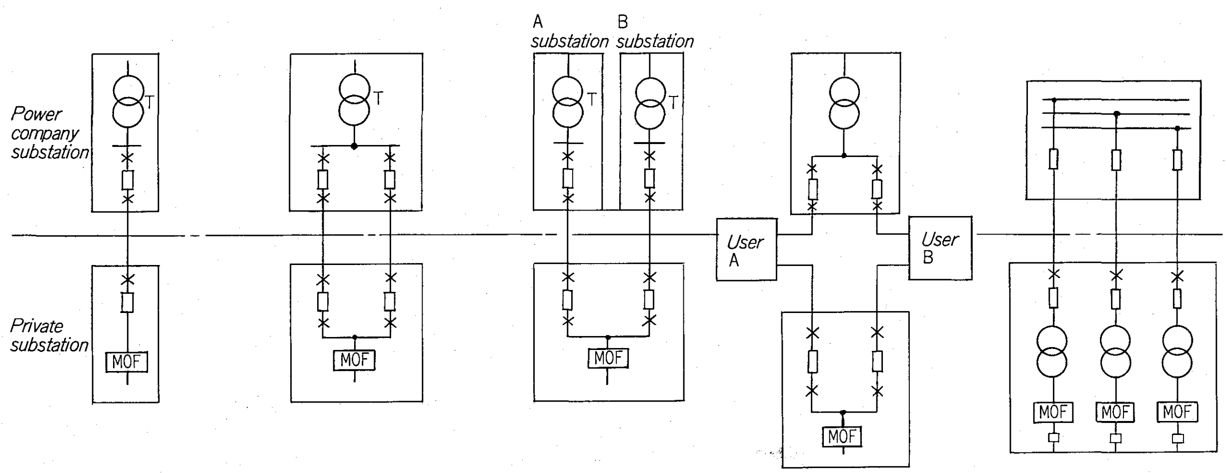
To increase system reliability, it is recommended that the 2CB receiving system, for minimum, normal standby by used in water and sewage works (the power supply side can be from the same source).

The transformer system is normally divided into two or more banks and the primary side is automatically cut off by insertion of the CB when there is a bank fault. So that complete interruption can be avoided.

In consideration of future expansions, the installation of bus line dividing disconnecting switches in the receiving bus line system can also shorten the power interruption time.

Fig. 2 shows a skeleton diagram of the receiving and distributing system of the Shibaura Treatment Plant of the Tokyo Sewage Department as an example fitting the above conditions.

The spot network receiving system in *Fig. 1(e)* was developed mainly from low voltage circuits of



(a) Single circuit receiving (b) Parallel dual circuit receiving (c) Dual circuit receiving from different network (d) Loop receiving (e) Network receiving

Fig. 1 Skeleton of receiving circuit

Table 3 Type of receiving circuit

Type of reception	Single circuit reception	Dual circuit reception	Loop reception
Characteristics	1) Construction is simple. Equipment expenses can be small. 2) Power interruption continues between power failure and recovery when there is a fault in the reception lines.	1) Power interruption time is kept short by switching over to the standby line, when there are power interruptions at the time of faults in the receiving lines. 2. Power interruptions when there is an abnormal circuit can be avoided by circuit changeover.	1) Since there is normally 2-circuit reception, there is no power interruption even when there is a fault in one circuit. 2) There is no power interruption during maintenance or inspection, since they are performed on one circuit at a time.
Diagram	(a)	(b), (c)	(d)
Economy (equipment investment)	Inexpensive	Medium	Expensive
System reliability	Poor	Medium	Excellent

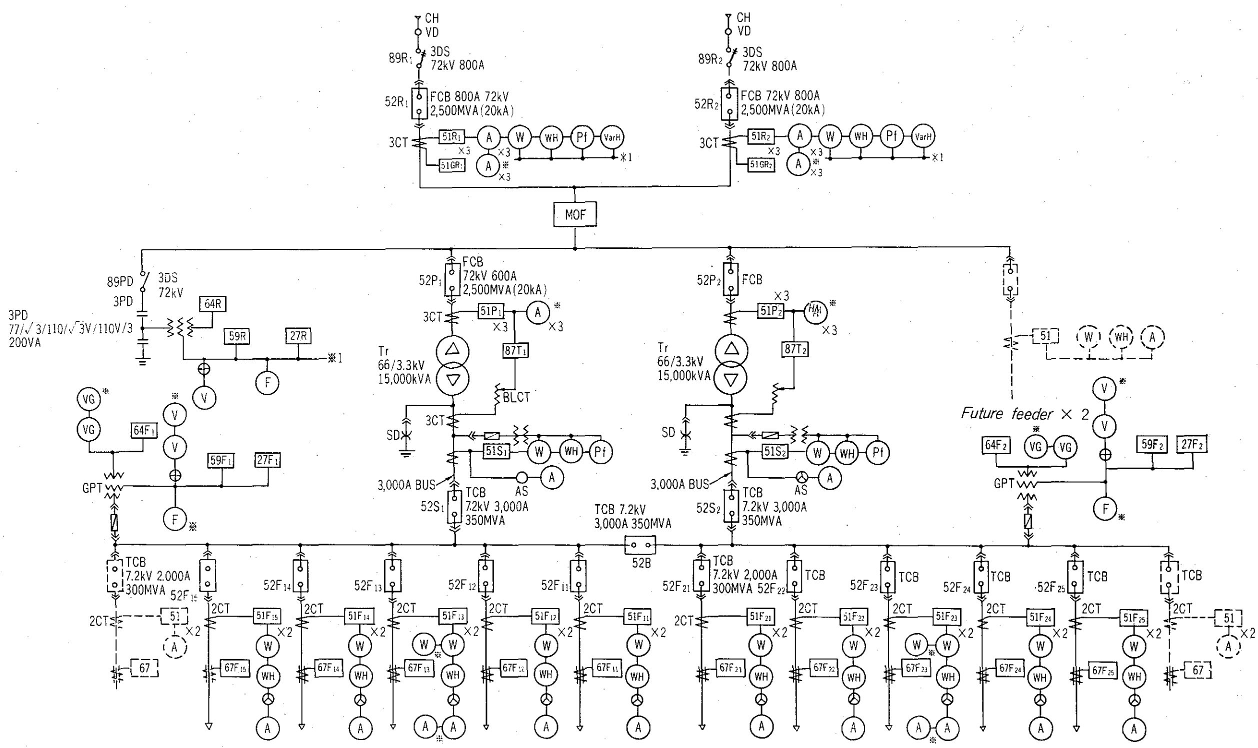


Fig. 2 Skeleton diagram of receiving and distributing system

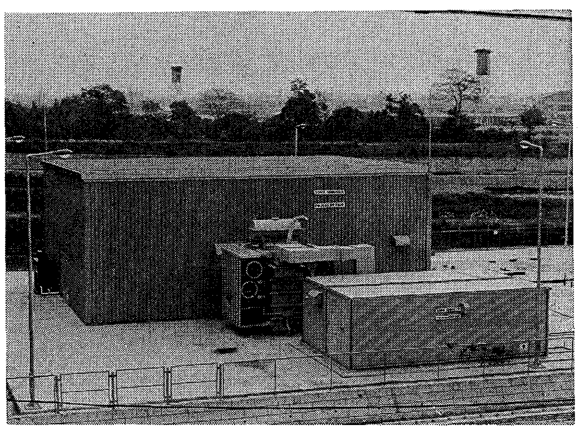


Fig. 3 Outline of 60kV outdoor cubicle

buildings because of the limitations of distribution networks of urban power companies. The system reliability is very high and recently, this system has been employed in high voltage networks in distribution pumping stations located in the cities.

As a special case for suburban facilities, 154 kV rather than 60 kV is (sometimes) supplied from power companies. In such cases, it is necessary to consult thoroughly with the power company about the selection of the receiving and protective systems for the trunk lines.

2. Forms of Substations

The form of the substation is affected by the receiving system. They can be classified as follows:

1) Outdoor steel frame construction
2) Outdoor cubicle construction
3) Indoor substation
4) Enclosed switching facility

All of these types have common features, but the outdoor cubicle type is most often used because of the simplicity of maintenance and inspection, smaller spaces occupied by the substations, noise countermeasures, economy, etc. *Fig. 3* shows an outdoor cubicle of a corrugated steel plate and a weather-proof top delivered to the Harada final treatment plant in Toyonaka.

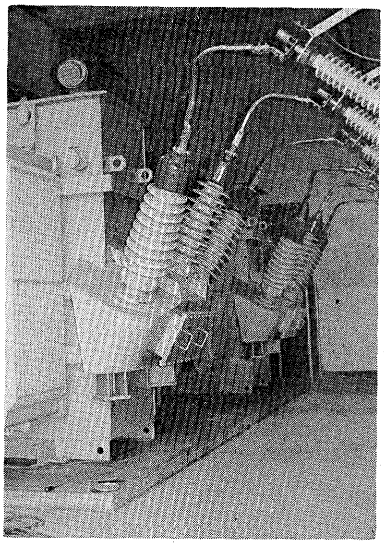
The indoor substations require somewhat higher equipment investment than outdoor cubicles because of the arrangement of the equipment inside structures. However, this type are superior to the first, two types for maintenance of the equipment and the environment in which the equipment is placed.

Fig. 4 shows a super high voltage indoor substation delivered by Fuji Electric to the First Mizushima sewage treatment plant in Kurashiki. Indoor type equipment was used and the space occupied was extremely small.

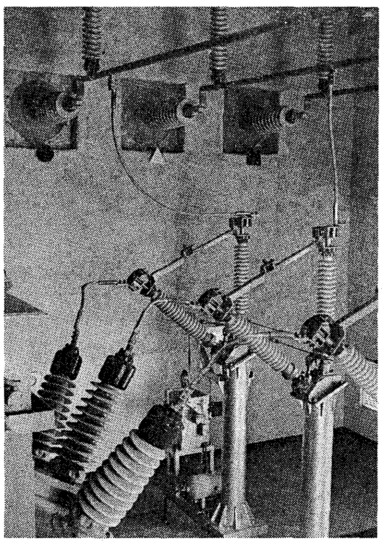
The enclosed switching facilities employs SF_6 gas which prove its excellence and the space occupied are also extremely small but the cost is high. Therefore, it is considered that such facilities will come into use in water and sewage works if they would increased in size.

3. Super High Voltage Circuit Breakers

The circuit breakers for the receiving points and transformer primary sides in super high voltage substations should be selected for highest reliability in



(a) Around main transformer



(b) Around bus lines

Fig. 4 Super high voltage apparatus for indoor substation

Table 4 **Standard short circuit capacity and applicable type of circuit breaker for receiving**

Rate voltage (kV)	Rated breaking current (kA)	Breaking capacity (reference value) (MVA)	Applicable breaker
24	25	1,000	Minimum oil capacity circuit breaker (TCB)
36	25	1,600	Minimum oil capacity circuit breaker (TCB)
72	20	2,500	SF_6 gas circuit breaker (FCB)
84	20	2,900	SF_6 gas circuit breaker (FCB)
	25	3,600	
120	31.5	6,500	SF_6 gas circuit breaker (FCB) (oil pressure drive)
168	31.5	9,200	SF_6 gas circuit breaker (FCB) (oil pressure drive)

both breaking characteristics and operating systems, since they provide the final back-up against fault currents in the user's facilities. *Table 4* shows the standard rated currents and the applicable types of receiving circuit breakers. Under these conditions, the operating duty specified in JEC181 must be guaranteed.

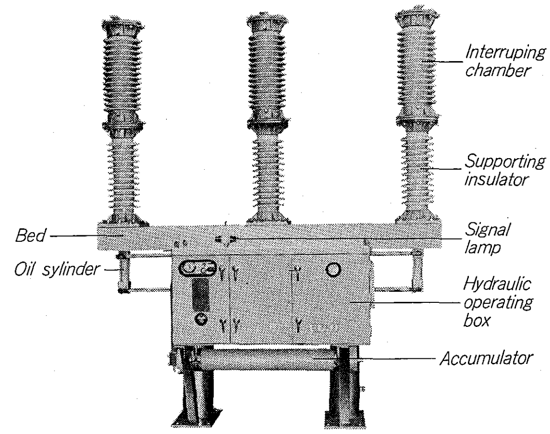


Fig. 5 72/84kV 31.5kA F-Schalter (oil pressure drive)

SF_6 gas circuit breakers are often used especially at 60 kV and over. The main reasons for this are that the breaking characteristics are excellent and maintenance is simple.

Recently, gas breakers with oil pressure drive for low noise at large capacities as shown in *Fig. 5* have started to be delivered to ordinary users.

III. HIGH VOLTAGE DISTRIBUTION EQUIPMENTS

1. Internal Distribution Systems

Water and sewage works facilities cover large areas and there are large numbers of loads scattered about as can be seen in *Table 2*. Therefore, sufficient ingenuity is necessary with the distribution systems for such works and these systems are generally designed as follows:

1) The distribution system must consist of circuits which are as easy to understand as possible and the protective relay system must also be simple.
2) The electrical network must be separate for each main piece of equipment and a secondary electrical room is to be located in each block. In these rooms, the networks are to be divided into those for high voltage loads and those for low voltage loads.
3) The system reliability is increased dual by circuit distribution from the substation or by doubling the equipment in the electrical rooms in each block.
4) When determining the distribution voltage, the selection is made from an overall standpoint with consideration given to the scale of the plant, the load capacities and the number of loads, and investigations made concerning the costs of the equipment according to the different voltage levels, as well as the expenses required for cable and wiring work.

Table 5 shows the relation between the voltage level and load capacity widely employed in water treatment plants. However, when the main transformer of the substation is more than 20 MVA, there are many cases when 6 kV is distributed on

Table 5 **Load capacity and suitable distributing voltage**

Internal distributing voltage	Load capacity	Main load
6.6 kV	200 kW～ several 1,000 kW	Pump, Blower
3.3 kV	approx. 100 kW～ 2,000 kW	Pump, Blower
400 V	10 kW～300 kW	Pump, Blower, Other auxiliary devices
200 V	several kW～ 70～80 kW	Illumination, Construction power, auxiliary devices, etc.
100 V	several kW～ 10 several kW	Illumination, Construction power, etc.

the high voltage side considering the short circuit current and the rated current on the secondary side.

2. Form of the Equipments

Distribution equipment can be divided into super high voltage distribution panels and low voltage distribution panels. Recently, the JEM1153-F_2 class single-phase totally enclosed distribution panels have been widely used in high voltage systems and the load center and control center systems have been widely used in low voltage systems.

As protective equipment, minimum oil circuit breakers and vacuum circuit breakers are widely employed in the high voltage class. However, the switching surges of the breakers themselves are small and excellent among the minimum oil circuit breakers.

In the low voltage class, distribution circuit breakers and air circuit breakers are used. They are protected by fuses and particularly in the 400 V systems, it is common to use earth leakage circuit breakers, earth leakage relays (ELR), etc. to detect correctly ground faults.

Distribution panels located outdoors have advanced from the conventional steel plate type to the aluminum housing type cubicle.

Table 6 shows experimental data related to the corrosion characteristics of the aluminum housing. It is evident that aluminum distribution panels compare very favorably with those made of stainless steel.

The exterior view of a super high voltage substation is shown in *Fig. 3*.

IV. TRANSFORMERS

The main points to be considered or investigated for the main drive power transformers and distribution transformers in water treatment plants are as follows:

1) Applicability of the capacity of the receiving point transformer banks
2) Possibility of parallel operation during future expansions
3) There must be harmony with surrounding areas in respect to noise.
4) High voltage transformers for distribution must be of the dry type whenever possible.

When determining the first point, i.e. the transformer capacity, it is necessary to anticipate the maximum power requirements from the plant demand factor, the load factor, the diversity factor, power factor, etc. and decide the transformer capacity.

Generally the following equation is used to determine the transformer capacity:

$$P_T = \frac{P_L}{\eta \times pf} \times \alpha \qquad \text{..............(1)}$$

where P_T : transformer capacity
P_L : equipment capacity
η : total load efficiency
pf : total load power factor
α : demand factor

The demand factor in water and sewage works is high when compared to the same factor in industrial plants. Generally, 60～80% is used for calculations.

Parallel operation is required in most cases because of the characteristics of water treatment plants and this is because two to three transformers are operated in parallel as the final form since two to three banks are decided as the equipment plans are completed in succession.

Therefore, the angular potentials, ratios, % impedance voltages, etc. of the transformers must be equal, and the capacity ratios of the transformers are within 3:1, or equal.

Table 6 **Data of atmospheric corosion test of aluminum and stainless steel**

Results of 20 years of exposure to atmosphere (unit: mils/year)

Test piece	Test site	Initial thickness (in.)	Environment	Exposure time			
				2 years	5 years	10 years	20 years
Aluminum 6063 (uncovered)	Kurc Eeach	0.064	Sea coast	0.015	0.004	0.008	0.003
	Kingston	0.064	Suburban area	0.014	0.010	0.006	0.005
18-8 stainless steel	Kingston	0.050	Suburban area	0.000	0.000	0.000	0.000
	Durban	0.050	Sea coast, industrial area	0.002	0.002	0.001	0.001

Note: 1) 1 mil=0.0245 mm
2) The values in the table show the minimum thicknesses.

(AL. Lab. K-RR-1174-71-15/02)

Table 7 **Ordinance (Tokyo) for prevention of noise**

Regions \ Conditions		Ordinary standard		Special standard	
		8 a.m. to 7 p.m.	6 to 8 a.m. and 7 to 11 p.m.	Near schools and hospitals	at 10 m from a loudspeaker (perpendicular from sound source)
Type 1	Exclusive residential, school areas, etc.	50 phons	45 phons	Same as left	60 phons
Type 2	Residential, green areas, etc.	55	50	5 phon less than standard on left	60
Type 3	Commercial, semi-industrial, industrial areas, etc.	60	55		60
Type 4	Among type 3 areas, those within 10m from roads of more than 11m in width	65	60		65
Type 5	Specially designated areas among busy streets	70	65		75

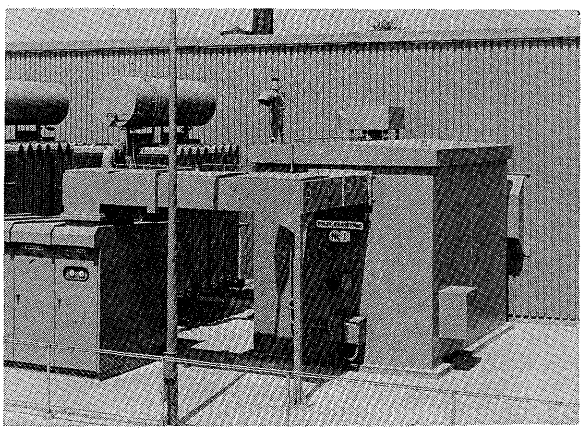


Fig. 6 Outdoor low-noise type transformer

The demands for low noise as in 3) require that the noise value be specified in accordance with the conditions of the surrounding areas and that it be in the 45∼55 phon class when the substation is located in business or residential areas. *Table 7* shows and example of the noise standards and *Fig. 6* is a photograph of a low noise type transformer.

The dry type H class distribution transformer is widely used in accordance with 4), because it is noninflammable and large fire extinguishing equipment is not needed in the electrical rooms, etc. This results in lower total equipment costs. The insulation degree of the dry transformers is lower than that of the oil-immersed transformers which is ideal for internal cable power distribusion. For primary switching devices, those with small switching surges such as very low oil capacity transformers or air load switches should be used.

V. EMERGENCY GENERATING EQUIPMENTS

Diesel generator equipment is usually provided for emergency standby power supply in water and sewage plants.

Since the water and sewage facilities operating conditions have a direct influence on the people's lives, not even momentary interruptions are possible and this makes emergency generating equipment necessary. Therefore, when planning the Diesel generating equipment, the following points must be especially investigated.

1. Generators

1) In calculating the generator capacity, the total load input kVA is to be calculated and the load demand factor taken as 100%.
2) The instantaneous voltage drop is to be within 25∼30% of the normal rated voltage. In the standard Fuji Electric equipment, there is recovery to within −3% of the rated voltage within 0.6 seconds.
3) The standard short-time overload is 150% of the rated capacity for 1∼2 minutes.
   Particularly when planning generators of medium and low capacities (less than 500 kVA), the capacity is often determined from the limitation of the instantaneous voltage drop during motor starting rather than the output during normal operation.
4) In the load closing sequence, closing from large starting current loads is best since the voltage drop is small and the generator overload factor can also be reduced.

In determining the generator capacity, the largest value from the (1), (2) and (3) values in *Table 8* is selected as the generator capacity.

Table 8 Calculation of generator capacity

(1) Normal operating capacity

$$G_1(\mathrm{kVA}) \geqq \frac{1}{pf_G}\sum_{i=1}^{n}\frac{p_i}{\eta_i}$$

(2) Momentary voltage drop

$$\Delta V(\%) = \frac{xd_e}{xd_e + X_L}$$

$$xd_e : \frac{xd' + xd''}{2} \qquad X_L : \frac{P_G}{P_e}$$

(3) Short-time overload

$$G_2(\mathrm{kVA}) \geqq \frac{1/pf_G \sum_{i=1}^{n}\frac{P_i}{\eta_i} + B_K \cdot p_K/\eta_K pf_K}{A_G}$$

where P_i : load output (kW) η_i : load efficiency
pf_G : generator power factor (=0.8)
P_G : generator capacity (kVA)
η_G : generator efficiency
xd' : generator direct-axis transient reactance (≒0.25~0.35)
xd'' : generator initial direct-axis transient reactance (≒0.2~0.3)
P_e : operating load starting capacity (kVA)
B_K : magnification of starting capacity in respect to rated capacity of group operating maximum kVA load (squirrel cage motor≒5~6)
P_K : group maximum load output (kW)
pf_K : group maximum load power factor
η_K : group maximum load efficiency
A_G : generator short-time permissible over load (=1.5)

2. Brushless Excitation System

The slip rings and brushes which are the sliding parts in AC generators present the greatest worry concerning operation and maintenance and also cause a large number of mechanical faults. Therefore, these problems can be completely solved with the brushless excitation system in which semiconductor elements are used and the AC exciter is coaxial with the generator rotor.

The degree of response of the excitation system which is the most important concern functionally is the same as that of the self-exciting compound system because of the use of an SCR control circuit.

3. Diesel Engine

1) The engine output (PS) becomes about 1.2 times the generator capacity (kVA).
2) The overload must be within 110% of the rated output in accordance with the engine characteristics and must be possible for 30 minutes to 1 hour.
3) Noise, vibrations and exhaust

Since Diesel engines have very high mechanical and combustion noises, the noise at 1 meter away is about 110 phons and even at the noise muffler outlet, it is normally 70 to 80 phons. Therefore, it is necessary to consider the attachment of a low noise type muffler, etc. in addition to the dampening effects due to separation from the plant premises boundaries, especially in areas where noise prevention standards, etc. are severe.

Table 9 Determination of engine capacity

Engine output calculation equations

(1) Normal operating capacity

$$E_1(\mathrm{ps}) \geqq \frac{\sum_{i=1}^{n}\frac{P_i}{\eta_i}}{0.736 \times \eta_G}$$

(2) Short-time overload

$$E_2(\mathrm{ps}) \geqq \frac{\sum_{i=1, i\neq K}^{n}\frac{P_i}{\eta_i} + B_K\frac{P_K}{\eta_K \cdot pf_K}\cdot pf_{SK}}{0.736 \times \eta_G \times A_e}$$

(3) Momentary load closing

$$\text{Load closing limit } (\%) \leqq \frac{9\sim 11}{P_e}$$

$$P_e = \frac{C_e \cdot N_e n}{P_E}$$

where η_i, η_G, B_K, P_K, pf_K, η_K P_i are the same as in Table 8.
0.736 : 1 ps=0.736 kW
A_e : engins short-time over load rate (=1.1)
9~11 (kg/cm²) : limiting value of net average effective pressure for load closing from no-load
P_e : engine net average effective pressure (kg/cm²)
C_e : constant determined by type of engine
N_e : output per cylinder (ps/cy)
n : cylinder number
pf_{SK} : group maximum load starting power factor
P_E : engine output

Even when fixed to a stationary base, the Diesel engine vibrates about 1/100~5/100 mm and is separated from the structural base. Therefore, recent trends have been to use engines with highly elastic rubber or anti-vibration springs, or common bases with the generator.

The ventilation required for the generator room is the sum of the ventilation required to maintain the temperature in the room constant (always under 40°C) and the amount of ventilation required for engine combustion (0.1 m³/ps.min.). The engine capacity is determined according to the equations in *Table 9*. The highest values among the (1), (2) and (3) values is selected as the engine capacity.

Fig. 7 shows an engine set which was delivered to the Iriezaki final treatment plant of the Kawasaki sewage department.

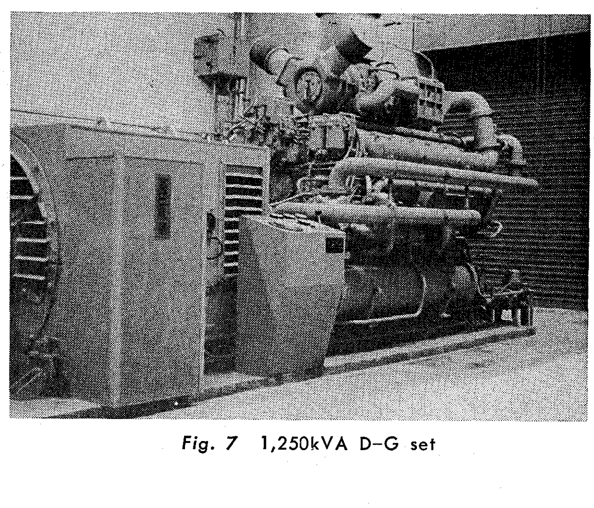


Fig. 7 1,250kVA D-G set

VI. CONSTANT POWER SUPPLY EQUIPMENT

In recent pumping stations, filtration and treatment plants, there is naturally automatic operation control for the individual devices as well as automatic operation for all of the equipment systems within the facility or complex, high level control from a centralized control room, etc. Under such conditions, the use of computers has greatly increased.

To ensure quality, the power supplies for the computers and instrumentation must not be interrupted. Therefore, in addition to commercial power supplies, constant power supplies (CVCF) which can supply constant voltage and constant frequency power have become indispensible.

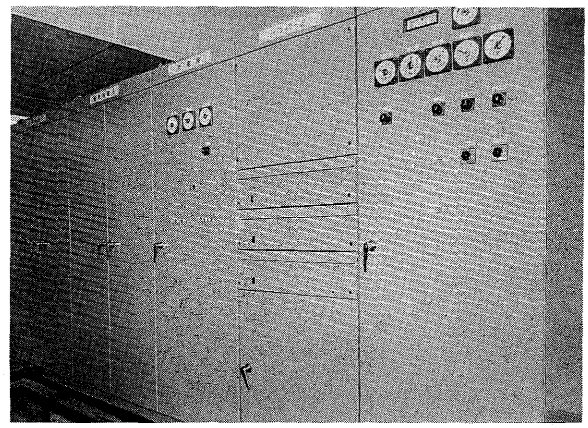


Fig. 8 Outline of 30kVA constant-voltage/constant-frequency inverter

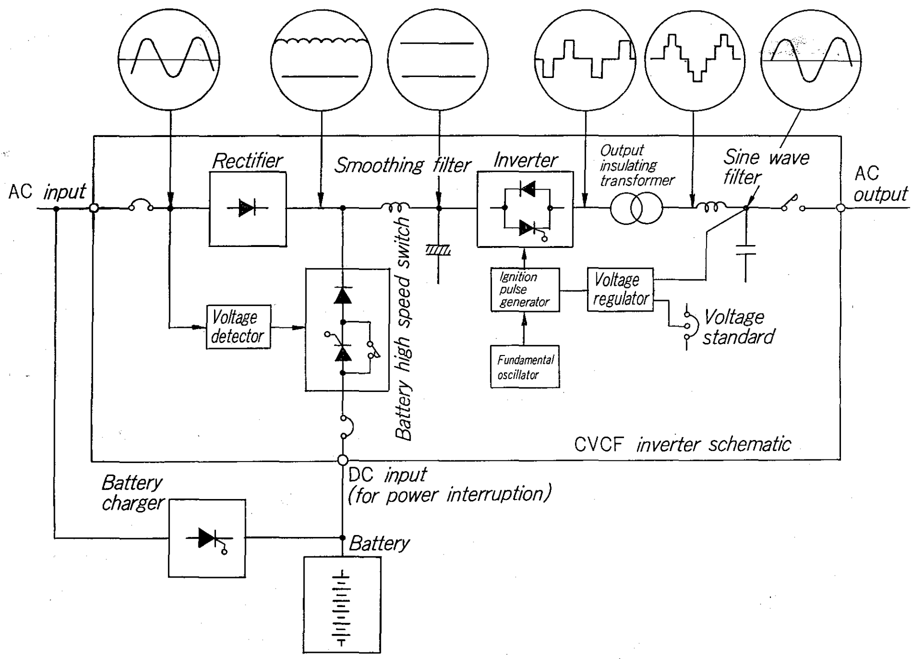


Fig. 9 Skeleton diagram of constant-voltage/constant-frequency inverter

The capacities of the CVCF can be determined by totalling the computer and load (process control device) capacities and allowing for some margin. However, considerable care must be taken in selecting the capacity especially when there are loads with high initial surge currents such as computers and transformers.

Fig. 8 shows a constant voltage/constant frequency inverter delivered to the Seibu filtration plant in Saitama prefecture and *Fig. 9* shows the standard circuitry of the CVCF.

VII. CONCLUSION

In water treatment plants, there will have to be both qualitative and quantitative improvements in the future because of the utilization of higher levels of water over wider areas. In this respect, electrical equipment is becoming very important for the supply of stable, high quality power mainly for plant drive.

In particular, receiving and transformer equipment must be planned, designed and installed to fit in with normal plant expansions and renovations.