ELECTRICAL EQUIPMENT FOR ELECTRO-CHEMICAL INDUSTRY

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In Japan with its rather poor natural resources per capita, electric power generated by hydraulic power is relatively abundant, having a considerable reserve for future development. It is quite natural that electro-chemical industry, making use of the only resources, forms the basis of our economic life and must make a progress ahead of others. This conception is quite reasonable if one realizes that increase of food production by chemical fertilizir, self-support of fibrous materials by chemical fiber and acquirement of foreign currency by exporting them are all naturally related with.

In fact the chemical industry is the biggest power consumer of all industries, its amount in 1953 reaching 37% of the total power generated (approximately 19×10^6 MWh). If the electric power development now under way has been completed, much larger power consumption will be expected. Table 1 shows the production of the principal electro-chemical goods and electric consumption. Especially large consumers of electric power in the chemical industry are roughly devided into an electrolytic group covering the water electrolysis of ammonium industry, the salt-water electrolysis of soda industry and the refinement of aluminium industry, and another electric furnace group such as carbide industry and lime nitrogen industry. The main electrical equipment employed in the industry is said to be constituted of current converting apparatus and transformers for electric furnaces.

Table 1. Production of principal electro-chemical preducts and electric power consumption

Article	Production 10^3 ton (1955)	Electric Power Consumption 10^6 kWh (1955)
Sulphate Ammonium	2, 075	3, 295
Caustic Soda		
{Electrolytic process	242	} 1, 000
{Ammonium process	287	
Carbide	573	1, 995
Lime Nitrogen	487	212
Aluminium	53	1, 035
Soluble Phosphatic Manure	229	229
Electric Pig Iron	125	327
Ferroalloy	143	965

There are manifold kinds of machines for the foregoing purposes. In their selection it is imperative that the kind of products, manufacturing process, scale of factories, supply of electric power and other allied conditions must be taken into account. The followings are the description of the merits and demerits of varied apparatus and also of a few practical example built by our company.

I. D. C. SOURCE EQUIPMENT FOR ELECTROLYSIS

Electrolytic industries that call for direct current have multifarious sorts; electrolytic soda, electric plating, metal refining of copper, zinc and nickel, fused electrolysis for aluminium, production of ammonium sulphate and many other are included. Of all the industries, those of large scale and consume electric power most are water electrolysis, aluminium refinining and production of electrolytic soda.

The scale of one production unit of these industries and one unit of electric power consumption are given in Table 2.

The D. C. source for these electrolytic cells, except in the cases where the factory is built at the site of water power generation and a D. C. water turbine generator is put to direct use for the purpose, is mostly available from various machines converting 3 phase alternating current of 3~140 kV into direct current.

No other machines than these converting apparatus have made such a marked progress for the last quarter century; starting from motor generators, they have gone through an evolution to rotary converters, multi-anode mercury rectifiers and single-anode mercury rectifiers and in succession.

Table 2. Voltage and current of various electrolytic cells

	Electrolysis Voltage per one Cell	Terminal Voltage per one Cell	D. C. Voltage for one Series	D. C. Current for one Series
Water Electrolysis	1.48	1.9~2.6V	250~800V	8,000~15,000A
Aluminium	1.15	4.5~7	300~700	30,000~60,000
Caustic Soda				
Diaphragm Method	2.3	3.4~4.0	200~600	3,000~15,000
Mercury Method	3.1	4.2~4.8	100~300	6,000~30,000

These past several years have seen another wonderful development in contact converters and selenium rectifier.

1. Contact Converters

As is clear in Fig. 1 showing overall efficiencies of various converters (including transformers) no machine is so efficient as the contact converter at every voltage. In the old practice a number of series electrolytic cells are increased in the water electrolysis or refining of aluminium so that they are operated in the region of higher efficiency with higher source voltage. But in the soda electro lytic cells the increase of series cells bring various difficulties, and the raising the source voltage is unadvisable. A rotary converter of high efficiency at low voltage and a single-anode mercury rectifier in a particular case have been employed. The latest trend in the mercury method soda electrolytic cells or the refinement of aluminium and magnesium by the fused salt electrolysis is to reduce the number of series cells and enlarge the current capacity of each cell, thus improving the efficiency of electrolysis and simplifying the additional facilities. The current capacity is raised as high as 40,000 amps. in the former and 100,000 amps. in the latter.

The contact converter is proved to have higher efficiency by 4~5% than any other converters in the range of 100~500 volts, which promises the exclusive employment in this region hereafter.

Since the first unit of contact converter of 250 volts 5,000 amps. was completed in 1951, the company has delivered to factories and refineries in 11 different sites 21 machines, the capacity totalling 150,000 amps.

The contact converter consists of a mechanism to open and close 6 contacts in synchronism with the source frequency and the commutating reactors to extend the zero current period of A.C. current waves to operate the contacts without sparking.

The early product of the company was in a very economical design adopting a 3 commutating reactor system in which such a reactor is inserted to each of 3 phase A. C. buses, thus cutting down materials. (Refer to Fig. 4 a). But for this construction comes in such a restriction as to complete the rectification of A.C. half waves within 180 elective angles, which narrowers the range of voltage adjustment; the stator of a synchronous motor is to be moved to shift the period of opening and closing the contacts for the adjustment of the output voltage, with result that a voltage adjustment to a large extent brings about closing the contacts while there is a considerable voltage difference between the contacts which shortens their life a good deal. To overcome these defects, a 6 commutating reactor system is adopted in the building of the latest machines, in which 3

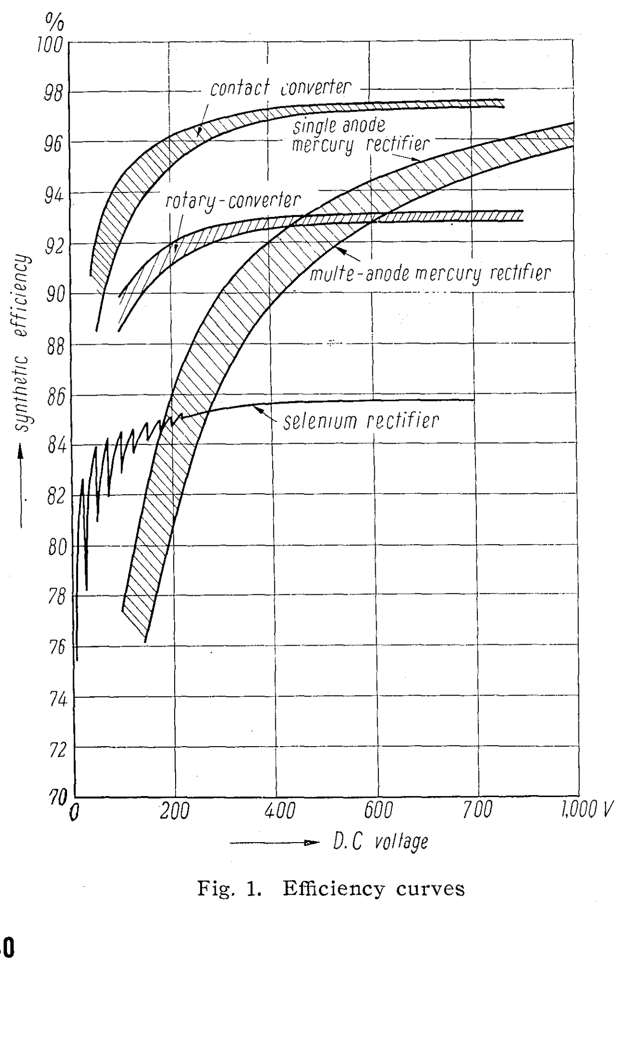


Fig. 1. Efficiency curves

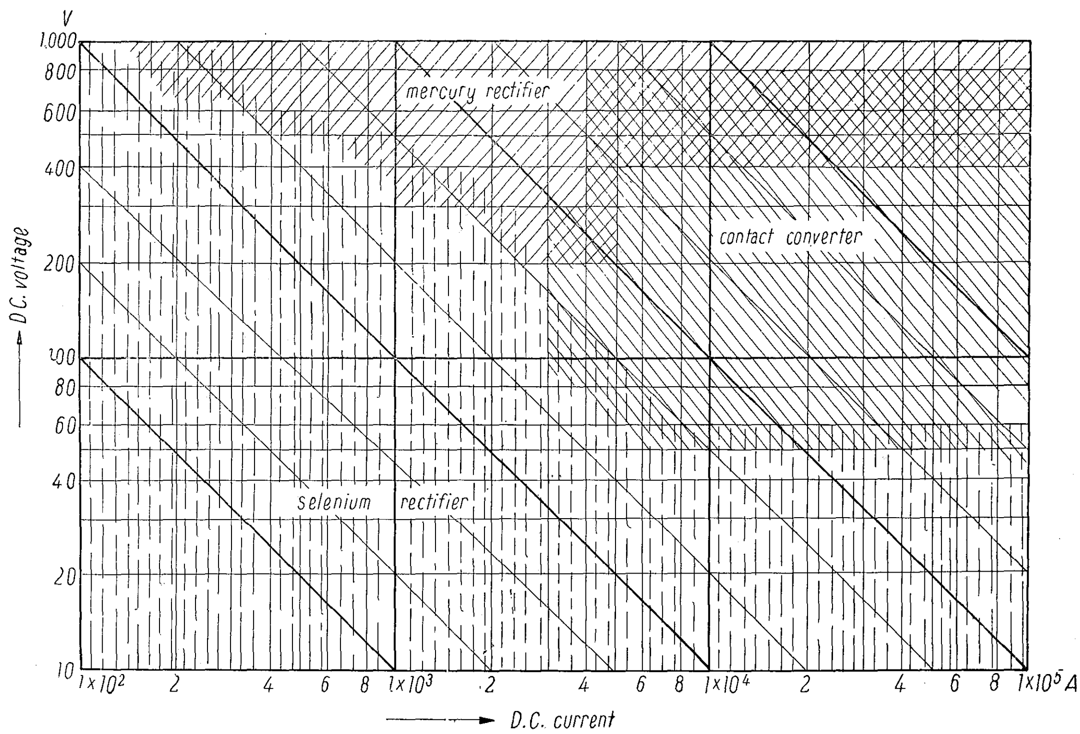


Fig. 2. Application fields of various converters

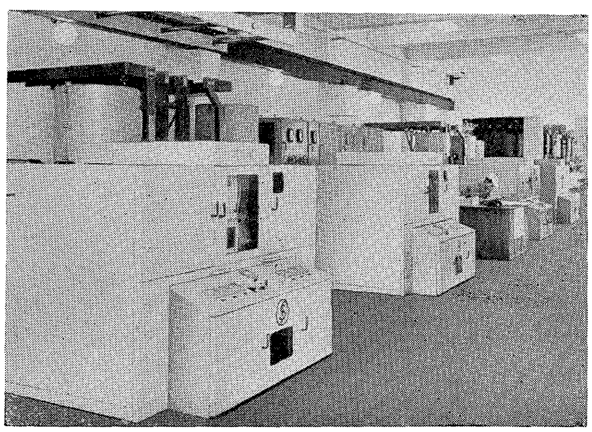


Fig. 3. Layout of contact converters

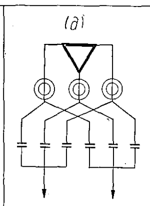
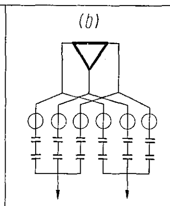
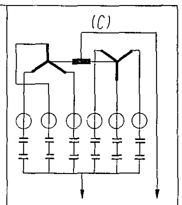
	(a)	(b)	(c)
connection			
voltage	400V	500V max 800V	250V
current	5,000A	6,000A	12,000A
number of contact point	6	open-circuit 6 close-circuit 6	open-circuit 6 close-circuit 6

Fig. 4. Connection diagrams of varied contact converters

phase A. C. bus is divided into positive and negative poles, each provided with one reactor–6 reactors in total on the device. (Refer to Fig. 4 b)

This system inevitablly bring forth the increase of required materials and cost compared with the old design. However, the range of voltage adjustment is extended to more than 50% and the contacts are always made to close under the no voltage state by the magnetic control of the commutating reactors. Their life becomes so long as to stand more than 6 months. The contacts are divided into those used for circuit-closing and circuit-opening, each driven by a separate motor. By connecting them in series and shifting their phase of opening and closing, ideal adjustment of overlapping angle is thus made available.

As one of varieties in this system, there is a double star half wave rectifying connection provided with interphase reactors. (Fig. 4 c) In this case the output current of the contact converter becomes twice as much as that of 3 phase bridge connection (Fig. 4 a and b) and it is very advantageous for low voltage and high current application. But the capacity of commutating reactor per kW is the same, while the capacity of windings of the transformer increases a little.

The contact converter should be handled with special care not to expose it to dusts and corrosive gases in the selection of the installing place. For the protection of the apparatus itself, further close attention has been paid in the design of new type contact converters, which are placed inside of a steel cabinet together with a cooling air circulation

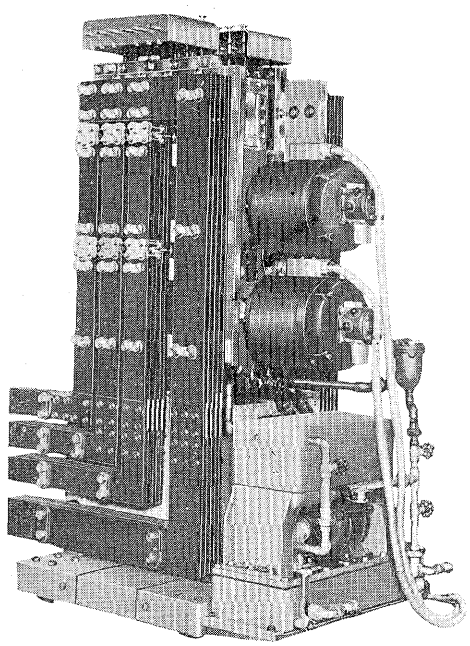


Fig. 5. New contact converter

device so as to avoid the intrusion of gases and dusts. Relays and switches on the switchboard are built in a sealed-in construction with electro-plating and coating on them for careful corrosion prevention.

In the contact converter, similar to the mercury rectifier, $n \pm 1$ times higher harmonics of the rectifying phase number, are generated on the A. C. side of the line and distort the wave-forms of the A. C. voltage and current. Therefore, increase in the capacity of the equipment may bring about inductive disturbance to communication lines, overheating of phase advancing condensers or ill effect on the rectification characteristics of the machine itself. To overcome these troubles, it is desirable to increase the number of phase in rectification as many as possible. In the contact converter, 3-phase bridge connection is mostly in use and 6-phase rectifying wave forms are available by means of 3-phase transformers. If the transformer secondary windings are divided into two groups of delta and star connection and a converter is connected to each group, 12 phase rectification is available with relative simplicity, being a great advantage of this design.

2. Mercury Rectifiers

In Japan mercury rectifiers have been almost exclusively employed for past two decades as a source of electrolytic power of a large scale. Rotary converters were once in use before the introduction of mercury rectifiers which however, have superseded the converters because of good many advantages of the rectifier over the converter such as higher efficiency at above 500 volts, simpler installation as a stationary apparatus and easier maintenance and operation, to which further added is a technical progress in the design itself.

For most of equipment built before 1946 and still in active operation now, multi-anode water-cooled type rectifiers rated from 5,000 to 6,000 amps. are extensively used. Those types built by the company and supplied for the electrolytic purpose amount to more than 110 units and over 500,000 amps. After that single anode water cooled rectifiers were completed (Fig. 6). Compared with the multi-anode type, they have small arc voltage drop and so much higher efficiency, which make them fitting for the conversion of large currents.

In 1953 multi-anode air cooled sealed type rectifiers without exhausting pumps were completed (Refer to Fig. 7). They require no troublesome work of maintaining vacuum, and the maintenance and operation have become markedly simple. Small floor spaces and no cooling water make this type unit very appropriate for medium capacity equipment which calls for electric current somewhere about 2,000 amps. Any larger current can be well taken care by connecting several units of there rectifiers in parallel with one transformer.

The mercury rectifier is little affected by unbalance or sudden drop of A. C. source voltage or other fluctuation. Because of no moving parts their maintenance costs are greatly reduced. It is also one of great advantages that large short circuit current can be quickly interrupted by means of a control grid in a large installation in which a number of rectifiers are connected in parallel.

In large capacity equipment at above 600 volts, their efficiency is approaching to that of contact converters and their cost is coming down. These features added to the foregoing advantages make these rectifiers comparable with contact converters. Which is more advantageous is left to the problem of future development.

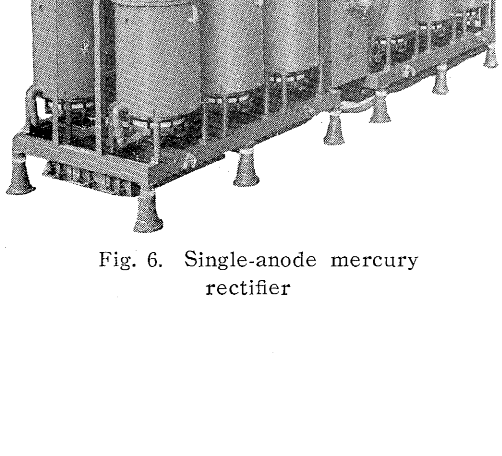


Fig. 6. Single-anode mercury rectifier

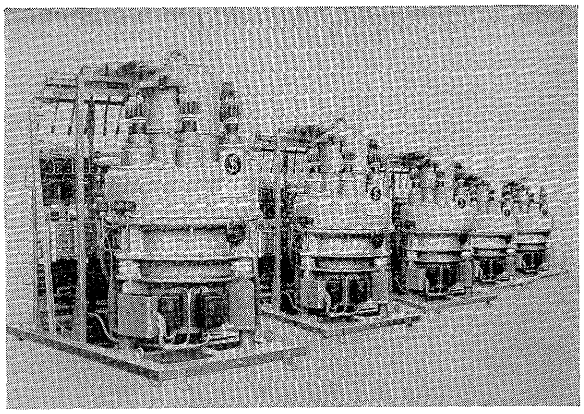


Fig. 7. Sealed type mercury rectifier

3. Selenium Rectifiers

For these several years selenium rectifiers have been making a great stride in their characteristics on account of progress in the process of producing selenium rectifying discs. Uniformity of products and advanced cooling method have made possible of building high current capacity units. For electrolytic application, dry type air-cooled or oil circulating oil-cooled rectifiers have come to be widely used. Fig. 9 illustrates the one used for water electrolysis cells to produce hydrogen gas for annealing furnaces. It is of an oil-immersed type to guard against gases and moisture, provided with an oil circulating pump inside and oil coolers of water cooled system at both sides.

By properly combining the rectifying discs in series and parallel, selenium rectifiers are built to have any desired output with costs almost in proportion to kW. They are most suitable for small and medium capacity installations where the contact converter or mercury rectifier is not justifiable from the cost of operation. In the requirement of small and medium capacity power sources for electrolytic refinement of metals, electrical plating, water electro analysis or intermediate plants for the study of new type electrolytic cells, motor generator, rotary type mechanical rectifiers or glass bulb mercury rectifiers have long been employed. But selenium rectifiers, because of no articles of consumption and easy maintenance and operation, will be sure to replace them in the future.

The voltage adjustment of the selenium rectifier depending on the use, is made by ordinary induction voltage regulators, tapped transformers or saturable reactors. Care should be taken in the selection, as the installation cost may greatly differ according to the range and process of the voltage regulation.

The internal losses of the selenium rectifier are proportional to the number of rectifying discs connected in series. As the output voltage increases approximately 24 volts, one disc is to be added to the series group. Therefore, when the number of series cells in the electrolyzer is reduced in operation, too many number of selenium rectifying discs are left in the circuit, with result that the set runs with a considerable low voltage, aggravating the efficiency in a long operation. In such a case, the selenium rectifiers, as shown in Fig. 9, are divided into several groups and connected in series; a number of series discs is sometimes adjusted depending on the operating voltage to maintain high efficiency all the time. The voltage regulator is to be attached to one unit of rectifiers in this case, and the expense will be saved a good. The selenium rectifier, however, is still under development and its relatively low efficiency at present may be gradually improved.

4. Load Adjustment Devices

The power source for the electrolytic cells generally require the adjustment of voltage within a considerably wide range:

a. to adjust the electrolytic current.
b. to respond to the change of the number of series electrolytic cells.
c. to respond to the variation of the terminal voltage due to the change in the internal condition of electrolytic cells.
d. to compensate the fluctuation of the A. C. source valtage.

In Japan a greater part of electric power resorts to hydro electric power stations, and unbalance between supply and demand caused by a seasonal or even a daily fluctuation is to be made up by

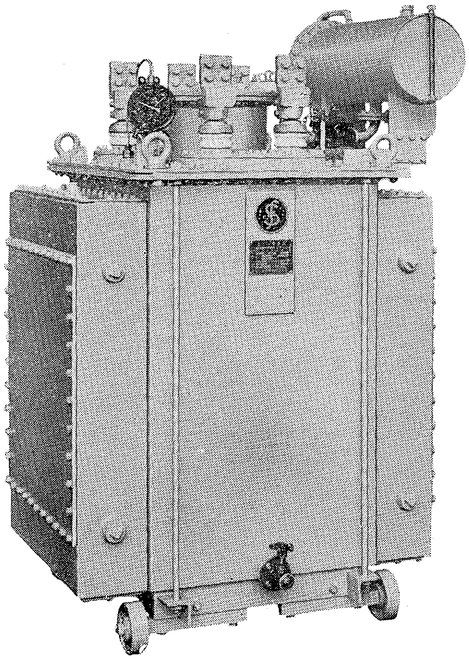


Fig. 8. 180 kW 90 V selenium rectifier for electrolytic industry

adjusting the consumption of power by the electro chemical industry. Especially the water electrolysis is made to contribute to the maintenance of the electric system cycle by adjusting the momentary consumption, because it needs enormous power demand of easily adjustable load. Hence, the power source for this water electrolysis calls for converting machines capable of maintaining a high efficiency throughout the range of light to full load and voltage adjusting devices workable with frequency and within wide range.

In the aluminium refinery the flow of constant current all the time is a prime requisite to maintain electrolytic efficiency. But the anode effect is unavoidable to it and the decrease of alumina in the fused bath with the progress of the electrolysis causes the sudden rise of the terminal voltage from the ordinary state of about 5 volts per furnace to the extent 30～50 volts. When a good number of series furnaces are used, the incident may be doubled. To keep constant current flowing against this rise of the terminal voltage, the power source voltage must be automatically raised by 10～20%. On the other hand, in adjusting the production or overhauling the furnace, the number of series furnaces is reduced, whereas in the commencement of newly built equipment the number of furnaces is gradually increased, thus wide range of voltage adjustment becoming indispensable.

For continuous voltage adjustment, rotary converters and selenium rectifiers usually employ an induction voltage regulator. In the case of mercury rectifiers grid control is used and in the case of contact converters magnetic control of commutating reactors is used for the alpha angle control, that is, to have the rising of rectified current on each phase lag behind the rectified voltage phase to lower the voltage, thus performing one side voltage adjustment. In general an automatic continuous adjusting device of this kind is employed for adjustment of constant current by itself.

However, selecting a range of the continuous adjustment wide means using a large, expensive, induction voltage regulator. In the case of the alpha angle control, it leads to an unfavorable effect of lowering the power factor and distorting the wave form. To avoid it, many taps are provided on the primary side of the transformer and are changed over at no voltage or under load to expand the range of adjustment. In the contact converter, the under load change over is exclusively used, because the operation and stop are more complicated them the mercury rectifier.

When more than two sets of converters or

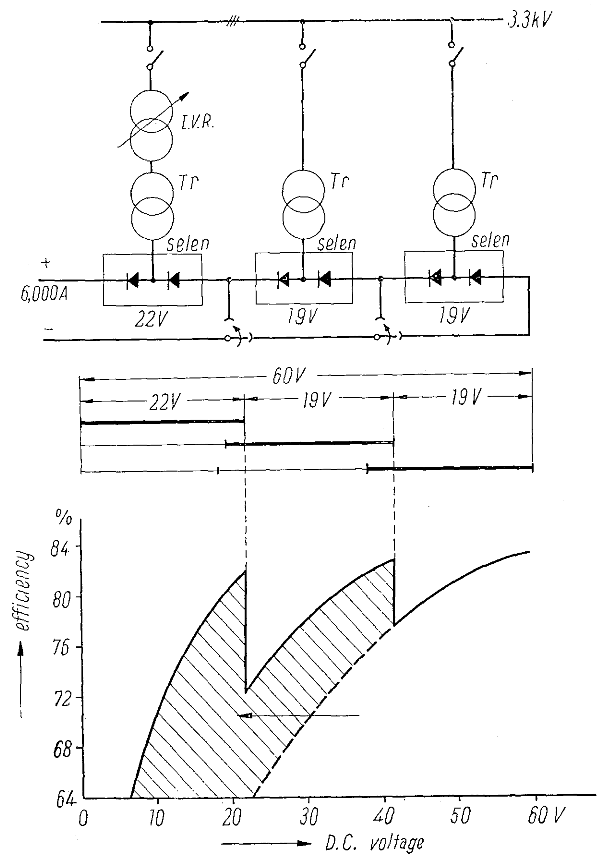


Fig. 9. Selenium rectifier separate-connected at 0–60 V

rectifiers are connected in parallel, an underload voltage adjusting transformer is commonly provided on the primary side of the main transformer, which is made tapless, small and sturdy. It may increace the floor space a little but is convenient in operation. In some cases, the price may become cheaper with this design, which is worth recommendable in large scale equipment.

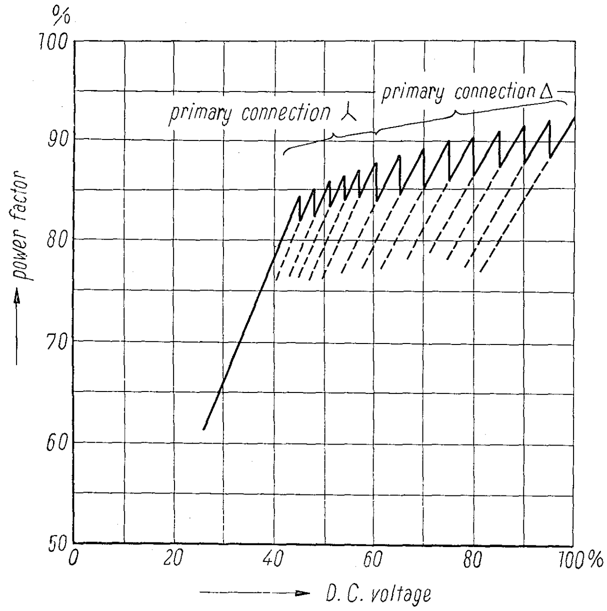


Fig. 10. Relation between voltage regulation and power factor for contact converter or mercury rectifier (In case of 5% tap in transformer)

II. ELECTRIC POWER SOURCES FOR FURNACES

An industrial division to employ electric furnaces for the production of carbide, ferroalloy and electric pig iron is another example of consuming enormous amount of power.

Transformers to be used for electric furnaces have very large secondary currents. In addition, their secondary voltage is to be adjusted within a wide range; they will be subjected to repeated overloading and 3 phase unbalanced loading. Gases, dusts and excessive heat generated by the nearby furnace aggravate the working conditions. Their design must be made to stand all the severity of the operation.

Our company has long been striving hard and has achieved the greatest manufacturing results in the development of transformers of this kind in Japan, the number of units completed, including the maximum capacity 28,000 kVA 100,000 amps, reaching more than 150.

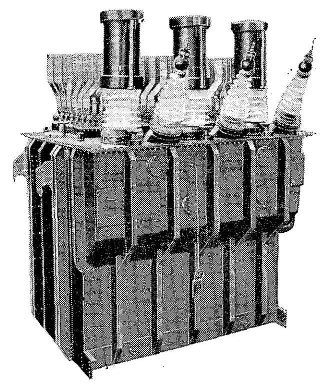


Fig. 11. Furnace transformer

1. Construction and Features

Transformers for electric furnaces have a relatively large single unit capacity. In the factory where several medium capacity electric furnaces are installed, usually receiving transformers are provided to supply 11∼33 kV power to the main distribution line of the factory, to which the furnace transformers are connected. Recently the design technique of the transformer has so advanced that it is a practice to connected them directly to the incoming line without the receiving transformers when large furnaces to the extent of 10,000 kVA or above at the smallest are newly installed. This practice, taking into account the circuit breaker equipment, brings economy to the installation cost and reduces the power losses. Such an arrangement as this is very convenient for future extension or alteration of the capacity of equipment.

In the transformer construction, the windings having the primary voltage of 3.3∼33 kV are made up of high and low voltage coils stacked alternately in the axial direction to form a sandwich construction as an usual practice. The secondary coils employed are of bare copper plates punched to a doughnut shape. When the primary voltage is 60 kV or higher than it so as to have the transformer directly connected to the overhead transmission line, the coils must be insulated strong enough to withstand the impulse waves by lightning or other causes. In this case the primary windings are made up of disc coils the inside and outside of which are connected one after another in series to form one single coil, which is in simple construction and producing satisfactory results. In the single coil construction, the stress of the impulse wave impressed between each coil is eased to the extent of 50 to 70% as compared with that of the twin coil.

Tap windings used with this transformer have, in general, such a wide range of voltage adjustment that the ordinary distributed arrangement of the conventional design can hardly meet the requirements. Then, being made in the form of an independent cylindrical coil, one tap is made to distribute uniformly from the top to the bottom of a main winding so as to suppress the fluctuation of impedance when the tap is changed and also to increase the strength against the impulse waves. The secondary low voltage winding in this case are to be of large current capacity, they can never be placed inside of the high voltage windings as in the ordinary transformer and are to be made up of bare copper plates bended to the cylindrical form, being placed at the outside of the high voltage windings the cooling method employed is a forced oil circulation system with an oil cooler of water or air cooled as a separate installation.

The most distinguished feature of the transformer for the electric furnace is its abnormally large secondary currents. When small or medium capacity units of not very high primary voltage are in use, the flat copper plates are employed without any modification to lead out large secondary currents in the former practice. This will cause the absorption of harmful gases, moisture or dusts from the part of the lead, which will injure the life of the transformer a great deal. To avoid this ill effect, the transformer of not only 60 kV primary voltage or above but also of small and medium capacity are provided with secondary terminals of water cooled pipe or sealed flat copper system together with a conservator. The conservator of the nitrogen sealed system is extensively used for large capacity installation.

The secondary side being of low voltage and high current, the power factor drops greatly on account

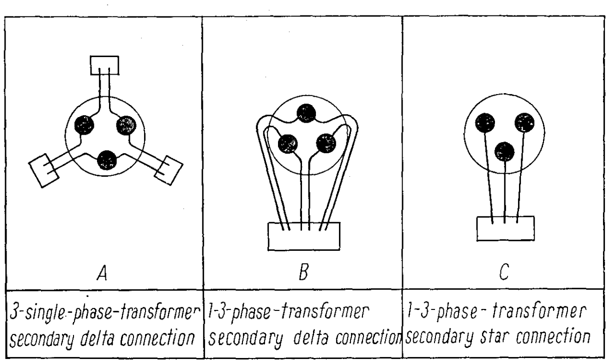


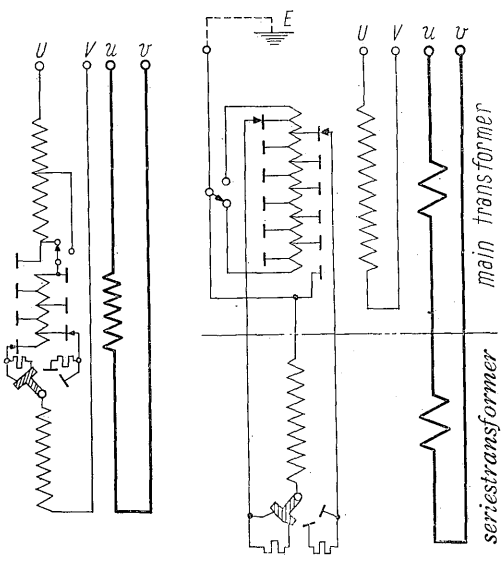
Fig. 12. Arranged example of electric furnace and transformer

of the reactance of the lead wire connecting the secondary terminal to the electrode of the furnace. To prevent it, as shown in Fig. 12, each phase of the secondary windings is led out to expose both positive and negative terminals without making a delta connection inside the transformer, the lead wires arranged with their positive and negative in a sandwich form are led to the electrodes so as to cancell the reactance, and the connection is for the first time made in delta at the electrodes. From economical reasons created by the improved dependability of the transformer, the latest practice is almost invariably employ 3 phase units. In the installation of large electric furnaces, 3 units of a single phase transformer are sometimes taken up from the difficulty of the lead wire arrangement to the electrode or for the convenience of individual voltage adjustment of 3 phase source. In a special case, single-phase transformers are installed in a delta arrangement around the furnace to save the lead wires and to balance 3 phase impedance as well (Refer to Fig. 12 A).

2. Voltage Adjustment System

The transformer for the electrical furnace calls for frequent adjustment of the secondary voltage within a wide range from the nature of the load. As previously stated, it is a specific feature in Japan to save the surplus electric power of the high water season or in the midnight by using it to turn out carbide or other electro chemical products. This will further need quick and big adjustment of the load in response to the momentary conditions of the demand and supply of power.

In the adjustment of the secondary voltage, it is a general practice to change over the equivalent taps of the primary windings, as the secondary windings are of a large current capacity. The method to change the taps under no voltage is economical, but it requires the opening of the circuit breaker on



(a) (b)

Fig. 13. Skeleton diagram of furnace transformer
(a) Direct tap-changing system
(b) Indirect tap-changing system

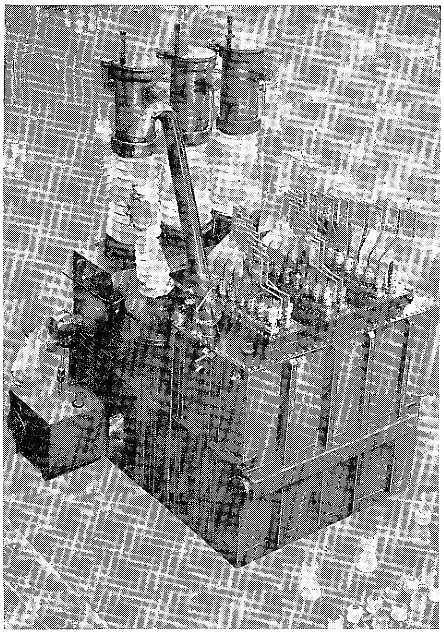


Fig. 14. Furnace transformer
3-phase 9,000 kVA 63,000/154~112 V

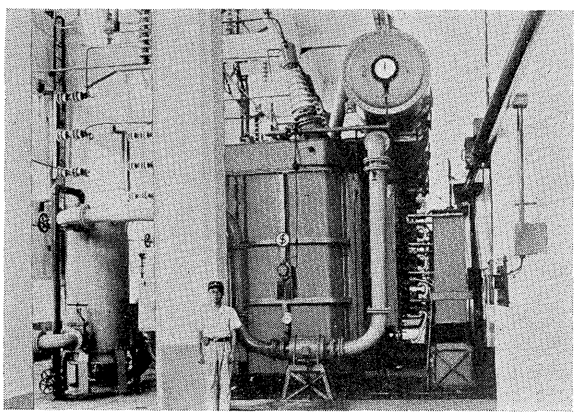


Fig. 15. Furnace transformer
3×single-phase 10,000 kVA 60,000/225~145 V

the primary side every time, which is not only tedious but also liable to disturb the primary side system, giving injurious effect on the life of the circuit breaker. This is especially fatal when the primary side is above 60 kV, so those with tap changer under load are mostly being produced.

Usually this tap changer is directly connected to the primary windings (Fig. 13 a). In the case of high primary voltage, and wide tap changing range, a series transformer for the voltage adjustment is provided and placed in the same tank with the main transformer. That means, the main transformer has tap windings in addition to the high voltage primary winding and the secondary windings for the furnace. The change.over of this tap windings varies the voltage to be impressed on the primary windings of the series transformer to effect the voltage adjustment. This impressed voltage on the series transformer may be reversed of its polarity so as to double the range of adjustment. (Refer to Fig. 13 b).

Fig. 14 shows a transformer with a tap changer directly connected to the primary winding of 60 kV. Fig. 15 is an installation of a transformer having the voltage adjustment by means of the series transformer.

The general practice of balancing 3-phase power of the electric furnace consists in the raising and lowering of the electrodes. But, moving the electrode within too wide a range gives ill effect to the internal conditions of the furnace. Separate adjustment of the individual 3 phases is sometimes employed for the balance of the power. Single-phase transformers are applicable to this purpose without any trouble. But 3-phase transformers need a special design such as to build them with 5-legged iron cores or 3 leg cored main transformers with a series transformer having 5-legged core, and 3 independent tap changes are provided to accomplish the purpose. Usually the secondary side is connected in star in this case (Fig. 12 C) with result that the power factor is lowered, but the required quantity of the secondary lead wire is only 85% of the ordinary design and copper losses are much reduced.

Table 3. Rating of transformer for chemical electric furnace

Article	Transformer Capacity kVA	Secondary Voltage V	Secondary Current A
Carbide	2, 500~30, 000	100~200	15, 000~100, 000
Ferroaloy			
Ferrosilicon	2, 000~15, 000	80~ 70	18, 000~ 75, 000
Ferromanganese	1, 000~ 3, 000	70~ 90	10, 000~ 22, 000
Ferrochrome	2, 000~10, 000	95~160	15, 000~ 50, 000
Electric Pig Iron	1, 000~ 5, 000	40~ 90	10, 000~ 35, 000
Soluble Phosphatic Manure	600~12, 000	80~400	4, 000~ 25, 000