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THE PROGRESS OF LARGE-CURRENT SILICON RECTIFIER EQUIPMENT FOR ELECTROLYSIS SERVICE

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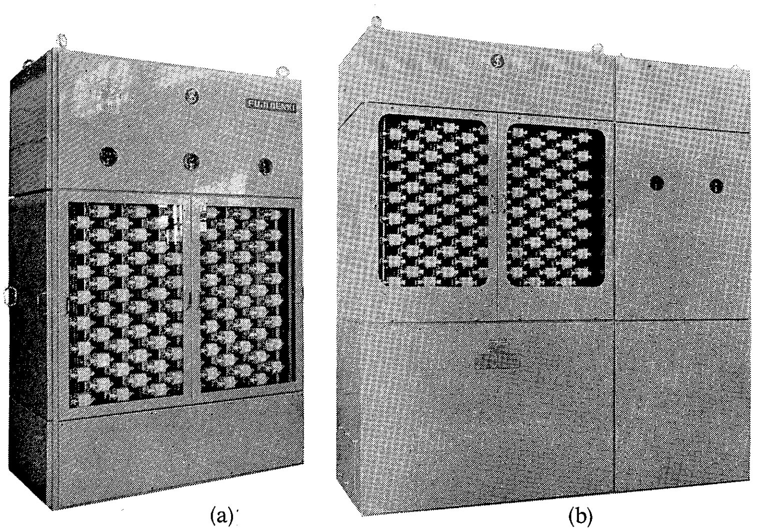
I. FOREWORD

The practical employment of silicon rectifiers, begun in 1958, has been continuing ever since. With the delivery of this large-capacity No. 1 equipment (220 v 10,000 amp 2 units) to Nippon Light Metal, the total capacity of silicon rectifier power supply equipment for electrolysis service manufactured and delivered by Fuji Electric has surpassed 2,400,000 amp, 700,000 kw.

The original rectifiers are of the most simply-constructed open forced air cooled by fresh air from outdoors. The self-blowing method of intake of cooling air from the lower portion and discharge to the upper portion is the most widely used; this is illustrated in *Fig. 1 (a)*. In order to prevent the internal portions of the rectifiers from becoming stained by dust or the corrosive gases often present in electrolysis plants, the cooling air is drawn through a filter from a location as high as possible in the rectifier housing. A more general method is to completely seal the building and circulate the room air through the re-cooling device of a water cooling system. The largest output of a single rectifier unit employing this type of system is the record 7920 kw 120 v 66 ka equipment delivered to the Shibukawa plant of Kanto Electric-Chemical.



(a) (b)

Fig. 1 Forced air cooled silicon rectifier

However, with this type of method, the rectifier housing gradually becomes complicated as the equipment capacity becomes larger. Moreover, a variety of conditions must be satisfied concerning the disposition of the equipment and the area and number of conductors required tend to increase. In case the mercury arc rectifier or contact converter units only are replaced by the new and more powerful silicon rectifiers, the necessary extensive renovation of the existing conventional house is not feasible, the major problem being the inevitable contact with the wall in the disposal of the purified air for air-cooling.

For this reason, closed cycle forced air cooled type rectifier comes into existence as shown in *Fig. 1(b)*. This rectifier has an air-to-water heat exchanger in which the heat exchanger is built in the rectifier assembly.

This has enabled simplification of the construction of the housing. Also, the conditions for the disposition of the equipment have been simplified to the point where the limit of output from the rectifier units has been increased.

Consequently, rectifiers having capacity more than 100 ka were installed at Kureha Chemical Industry, Kanto Electro-Chemical and Asahi Electro-Chemical etc., with minimum of cost to meet the increase in production by permitting increase of the output voltage. By insertion of boosting transformers and rectifiers more compact installation than conventionally used has been obtained. However, the connection of conductors between the transformer and the rectifier becomes more complicated as the output current of the rectifier unit is increased; these difficulties become apparent in performing this at the actual place of installation. Moreover, because the current in the bus bar is of rectangular waveform having peak value similar to the output dc current or of alternating current of rectangular waveform containing many high harmonics, the effective resistance of the conductor increases due to the skin effect. The reduction in power factor due to the reactance in this section cannot be ignored.

For instance, the calculated results indicate a 0.2% rise in efficiency and 1.8% in power factor (transformer capacity may be reduced accordingly) by shortening the length of the conductor in the 200 v, 20 ka rectifier by 4 meters.

In order to solve the above problem, there are no alternatives to connecting the conductor at the factory by locating it extremely close to the rectifier and shipping it out as is or combining the transformer and the rectifier into one unit. As the initial step in the solution of this problem, Fuji Electric has completed the direct system S-former in which the rectifier diodes are screwed into the tank wall of the transformer. In the autumn of 1963, two units of 120 v, 33,000 amp were delivered to Shibukawa Plant of Kanto Electro-Chemical.

Thereafter, Fuji Electric rationalized the equipment by applying many new techniques to perfect the water cooled rectifier in order to make it more compact and to raise its output. A new system of large current silicon rectifier equipment has been completed mainly for electrolysis applications. An outline of it will be given in the following.

II. DIRECTION OF ADVANCE FOR ELECTROLYSIS POWER SUPPLY-USE RECTIFIER EQUIPMENT

1. Problems Related to the Development

The objectives for the development included high efficiency, lower cost, elimination of unnecessary time for the maintenance and operation and long usage without troubles due to corrosive gases and dust in chemical plants or surroundings with high humidity such as found in the coastal areas with salt content. It was confirmed that these objectives hardly presented any problems to the reliability of the silicon rectifier diodes.

(1) Conservation of required materials by making the equipment more compact.

(2) Isolation from atmospheric influence by sealing completely.

(3) Elimination of the cost of constructing the housing by external installation.

(4) Reduction of maintenance time by utilizing a cooling system with high efficiency and simplicity.

These are the main technical problems. In addition, there are purely electrical problems concerning the elimination of reactance (due to local overheat, unbalanced currents) in case of large current and the rationalization of the receiving and distributing system; both will be explained later. The previously mentioned problems are all related to the problem of rationalization of the cooling systems for the rectifiers including the transformers.

2. Comparison of Cooling Systems

The most universally used coolants for silicon rectifiers normally are air, oil and pure water.

The values indicating the cooling capacity for these three substances are shown in *Table 1*. As the table clearly shows, the ratio of the capacity as a cooling medium for air, oil and water are approximately 1 : 10 : 100. *Table 2* shows a comparison of

Table 1 **Comparison of Different Coolants (Comparative values at 50°C)**

Coolant	Air	Oil	Water
Heat Transfer Rate (w/m °C)	0.028	0.12	0.642
Specific Heat (ws/kg °C)	1000	1900	4200
Density (kg/m^3)	1.09	859	988
Coefficient of Viscosity (m^2/s)	18×10^{-6}	9.3×10^{-6}	0.55×10^{-6}
Heat Transfer Rate from Metal to Media (w/m^2 °C)	~5* ~35**	350	3500

*) Still air **) Wind velocity 6 m/s

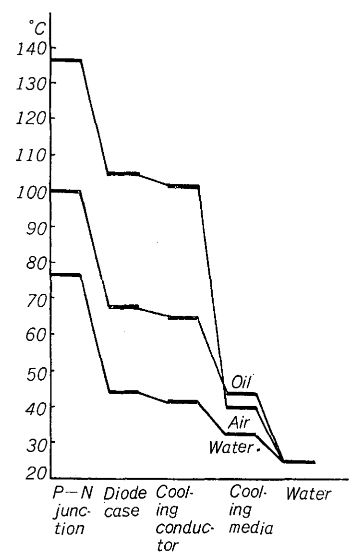


Fig. 2 Mean temperature in the cooling system of a silion rectifier with different coolants

the temperature differences of various sections when the silicon rectifier is subjected to various coolants such as forced air cooled with air-to-water heat exchanger, oil cooled with oil-to-water H.E. and water cooled with water-to-water H.E. with identical external conditions (identical output, identical number of elements, re-circulation with identical amount of water at a temperature of 25°C).

As clearly seen from this, it is noted that the temperature of the rectifier diode is considerably lower with pure water used as the coolant than the other two.

Conversely, it means that the amount of water required for cooling can be conserved considerably if the temperature of the rectifier diode is permitted to reach the same value as that of the forced air cooled system. It also indicates the possibility of economical operation of the equipment by using air at 40°C instead of water of 25°C for re-cooling.

With the exception of the dry type, the transformer which is combined with the rectifier can use only oil as the coolant due to its insulation characteristics. The cooling effect of oil as a coolant is approximately 1/10 of water, as mentioned previously, but is approximately 10 times that of air. The insulating characteristics are much higher than water and special consideration of electrolytic corrosion is not necessary. From a comparison of the merits and demerits mentioned above, the most suitable cooling system for large current (over several thousand amperes) silicon rectifier equipment to be used in staining environments such as chemical plants in this present age should be decided by the following considerations.

(1) In case the oil in the transformer is used for the coolant of the rectifier, it is not necessary to install a special oil flow line for the rectifier. Install a base plate on the tank wall of the transformer and install the rectifier diodes onto the plate, thus cooling the transformer and the rectifier element simultaneously with the oil inside the tank. This system is called the direct S-former by us. Its construction is simple compared to other systems where the transformer oil is drawn out once and forced-circulated inside the rectifier; also, needless to say, it is much more reasonable. In this case, oil-to-water heat exchanger would be more economical than oil-to-air heat exchanger.

(2) If much higher output (over several ten thousands amperes) is requered, or if it is not possible to use water as a re-cooling medium and no other method is available except using air of higher temperature, or if the transformer is installed separately from the rectifier due to the utilization of a standard designed item or must be designed as same as existing transformer, pure water with the greatest cooling ability as a cooling medium is selected and the forced water cooled system is used for forced circulation to the rectifier conductor interior.

In this case, the rectifier cubicle is installed directly to the side surface of the transformer tank. This single-unit construction is called the indirect type S-former by us. Either a water cooled or air cooled heat exchanger may be used effectively for the re-cooling of the water for the rectifier and oil for the transformer. Also, the fact that it can be completely sealed the conductor as well as the fuse in the cubicle are cooled by the water without a special heat exchanging device, is an important factor.

III. RATIONALIZATION OF DEVICES RELATED TO DEVELOPMENT OF SILICON RECTIFIER DIODE

Since the first silicon rectifier made by Fuji began operation in 1959, more than several ten thousand silicon rectifier diodes have been continuing operation day and night for electrolysis services alone. However, the results of the operation are in accordance with the initial expectations and both the stability and the reliability are perfect, with the trouble factor originating in the element itself statistically small enough to be neglected, so it may be considered trouble-free at the present time.

Accordingly, efforts for the development of the silicon rectifier diode in the past several years have been directed solely toward increasing (increase of withstanding voltage and current) the output per unit. However, the most epoch making item of all is the development for the system of mechanically connecting the silicon P–N junction to the case as well as the leads by pressure instead of soldering, as shown in *Fig. 3*.

This method has been perfected to completely overcome the defect of the soldering system with respect to the severe heat cycle in cases when the

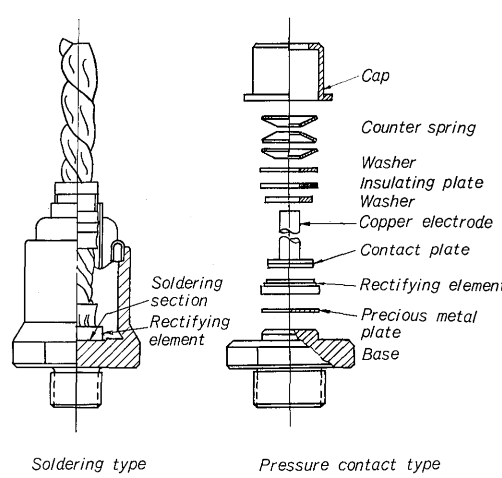


Fig. 3 Construction of silicon power diode

Table 2 **Current Ratings and Thermal Characteristics of Silicon Power Diodes**

Model	Contact Assembly Method	Rated Mean Forward Current (amp)	Overcurent, Commercial Frequency Half Wave, 1 cps (amp)	Permissible Continuous Junction Temperature (°C)	Heat Resistance of Rectifier Segment vs Case (°C/w)
Si 150	Soft solder	200	3800	140	0.2
Si 250-1	Hard solder	240	6500	150	0.2
Si 250-3	Pressure contact	280	7500	160	0.15

silicon rectifier is used for the railroad ersvice. However, the significance of this with respect to electrolysis is not in its withstanding of the heat cycle but rather the rise in the permissible operating temperature of the silicon element of the pressure contact method. (Refer to *Table 2*) This is very convenient for the purpose of selecting the coolant for the rectifier which is noted from *Fig. 2* and the the system for re-cooling as well. Especially, in the case of the direct type S-former where the rectifier element is screwed onto the side wall of the transformer tank, the difference between the permissible temperature for the junction of the soldering type of 140°C and the transformer oil temperature of 90°C formed by the ambient temperature of 40°C plus the standard maximum rise of 50°C is 50°C. Compared to this, the difference between the oil temperature and the permissible temperature of the pressure contact type of 160°C is 70°C. Because of this, the amount of heat transferred from the silicon P–N junction to the oil will be larger than that of the soldering type.

As a result, the permissible amount of temperature rise of the diode base plate exceeds the permissible amount of temperature rise of the transformer windings as far as the direct type S-former is concerned and it has become possible to design transformer-rectifier equipment more reasonably.

Also, this pressure contact method is convenient for producting a reverse polarized element by enclosing the P–N junction upside down within the case. The heat resistance will increase somewhat and the output current will decrease approximately 15%. However, the practical application of the reverse polarized element is very effective at the stage of making the direct type S-former of bridge connection compact or in the water cooled type rectifier, as will be explained later.

Furthermore, the unprecedented large capacity disk type silicon rectifier diode shown in *Fig. 4* has come to be used practically recently[4]. This allows fitting the diode directly to conductors with pressure and operating temperature exceeding that of the previously mentioned pressure contact type. Also, more current can be passed because the heat may be dissipated from both surfaces of the P–N junction. The construction is simple and it is possible to make the rectifier equipment of oil immersed type. Extraordinary further development through the application of the water cooling system is anticipated.

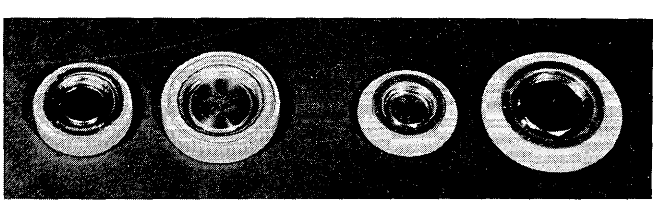


Fig. 4 Disk type silicon power diode

With respect to this type, the current flow direction of the rectifier may bc chosen readily by reversing at the time of fitting the diode.

IV. WATER COOLED TYPE SILICON RECTIFIER

1. Water Cooled Type Silicon Rectifier Bound for the Niigata Plant of Nippon Light Metal Co., Ltd.

As explained previously, the cooling capacity ot water is most superior. The recently completed water cooled type rectifier bound for the Niigata Plant of Nippon Light Metal will be introduced in the following, with concrete details of its construction. An exterior view is shown in *Fig. 5*. The center section consists of water circulation and water-to-water heat exchanger. One unit each of 760 v, 6000 amp water cooled type silicon rectifier is connected to the right and the left side. This equipment is to alter 20 units of water cooled type multianode mercury-arc rectifier installed during the war. The existing rectifier transformer (two 6000 amp mercury-arc rectifier units are connected to one

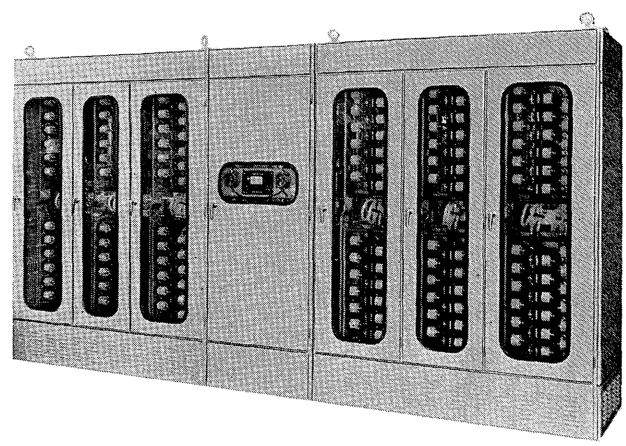


Fig. 5 760 v 2×6000 amp water cooled silicon rectifier

transformer unit) can be used as is.

One water cooled silicon rectifier unit shown in the picture is suitable for two existing mercury-arc rectifier units. The 26 mercury-arc rectifier units having the same ratings as those of the Kambara Plant of the same company have already been replaced by silicon rectifiers the year before last. However, that was the closed cycle forced air cooled type with air-to-water heat exchanger as shown in *Fig. 1* (*b*). In the case of the Niigata Plant, the water temperature for re-cooling use (circulating water for the mercury-arc rectifier) is 34°C, which is higher than the 28°C of the Kambara Plant. Water has been selected as the coolant for direct cooling of rectifier since using air as the coolant enlarges the equipment and is not economical. As a result, the number of silicon diodes decreased and the amount of water required for re-cooling of two

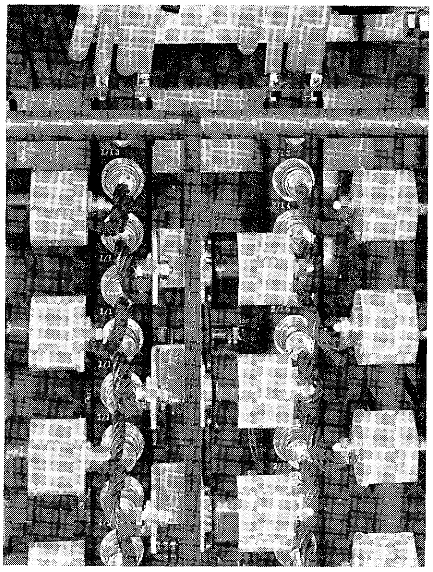


Fig. 6 Inner construction of water cooled silicon rectifier

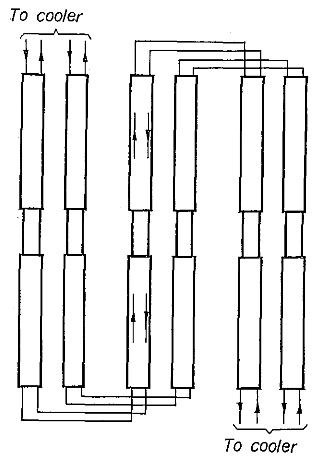


Fig. 7 Cooling system of rectifier

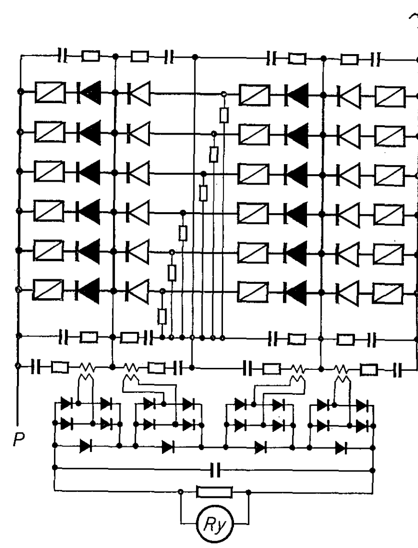


Fig. 8 Connection diagram of water cooled silicon rectifier

6000 amp units was almost halved from 240 liters to 125 liters per minute in spite of the 6°C higher than the case of the Kambara Plant.

2. Construction

The pressure contact type diodes are used and diodes are screwed on the direct water cooled conductor, as shown in *Fig. 6*. This conductor is made of copper extruded material with a hole pierced from top to bottom on both the right and the left sides to enable water flow. A total of 12 water cooled conductors inside one cubicle are connected through a special polyethylene hose which has been treated with radiation in order to increase its heat resistance; it is shown in *Fig. 7*. Consideration has been given not to create temperature differences on any conductors. With respect to the output voltage of 700 v, the three-phase bridge connection will be used for the newly produced equipment but, as explained previously, this equipment is to be used in combination with the existing rectifier transformer and hence the connection method will be 6 phase double star type. Accordingly, the inverse voltage will be more than twice that of the bridge connection. The parallel number of silicon rectifier diodes will be halved but the series number will be doubled; in this case the number of series diodes will be 4.

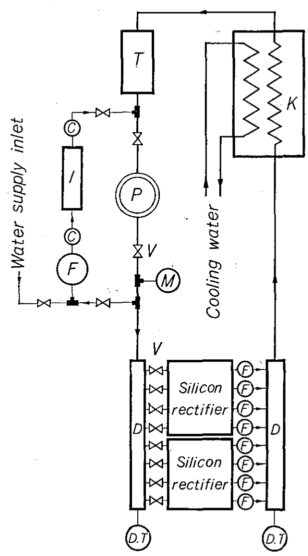
In the case of the air cooled system, the insulation between the diodes can be maintained by leaving a small space between the cooling fins right next to each other along the spaces of each of the series diodes.

Therefore, there is no effect on the series circuit at its side no matter how many diodes are connected in series; each series circuit can be protected by fuses. However, in the case of a water cooled system, all the parallel diodes are connected to the same electrical potential of one cooling conductor, only the necessary number of these being connected in series per group. Accordinly, if there should be at least one diode with reduced inverse voltage characteristics present in the parallel group, the apportioned reverse voltage of the entire group will be reduced and more than the permissible amount of reverse voltage will be borne by the other series connected groups. In order to avoid this danger, in addition to the fuse for the protection of diodes shown in *Fig. 8*, an alarm producing device has been added to each series group for cases when the permissible value of apportioned voltage is exceeded.

Also, among of the four diodes in series, two will be regarded as having reversed polarity; together with the properly polarized diodes, they are installed in the same water cooled conductor, combining the function of connection terminals for the purpose of series connection. Through each pair of water cooled conductors, a total of 24 diodes, 4 each in series and 6 each in parallel, are mounted. As a result, in spite of the large number in series, as seen in the exterior view figure in the previous section, it was possible to combine into a simplified form.

3. Cooling System

Fig. 9 is the water circulation system diagram. *Fig. 10* is a photograph of the equipment which is the interior of the center portion of the cubicle shown previously in *Fig. 5*. A glandless water pump is located at the bottom, a water flow meter with alarm contact for each diverting water path on top of it. In the center portion are located the conductivity meter for pure water, thermometer and the pressure meter. On top of the left rear of these is the water tank. The water-to-water heat exchanger can be seen above the right side. On the rear side



P:	Pump	*M*:	Manometer
K:	Heat exchanger	*V*:	Valve
T:	Pressure tank	*C*:	Specific conductance meter
I:	Ion exchanger		
F:	Flow relay	*D*	Distributor
D. T:	Dial thermometer		

Fig. 9 Cooling system diagram

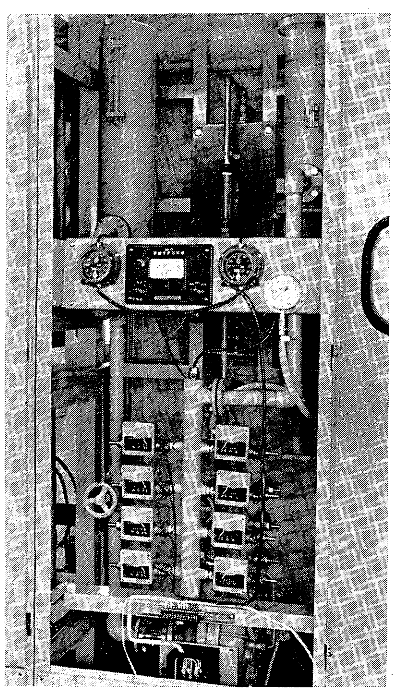


Fig. 10 Outside view of cooling equipment

of the water gauge is installed the cartridge type ion exchanger.

The distribution system is entirely constructed from either stainless steel or heat-proofed plastic material but, through educing of a small amount of copper ion from the cooling conductor of silicon rectifier diode, the electrical resistance of the pure water is reduced. In order to prevent electrolytic corrosion from occurring, the portion of the circulating water shown in the system diagram of *Fig. 9* is passed through the ion exchanger at normal times and restored. The resistivity of the circulating water is maintained normally at 10^5 to 10^6 Ω-cm. The circulation rate of the water for this rectifier of 9120 kw 12,000 amp is only 90 liters per min. The input power for the circulating pump does not exceed 2.2 kw. The generated power loss of the silicon rectifier is approximately $\frac{1}{10}$ that of the mercury arc rectifier. Because of this, the circulating water capacity can be small and while the latter was steel where the water touches, the former is copper. Furthermore, through the development of the construction material for the water system, the previously difficult ion exchanger can now be used effectively. Thus the problem of electrolytic corrosion accompanying the water cooled system has been solved and the water can be thought of as a potent cooling medium which is very different from the days of mercury arc rectifiers. This water cooling system is not only effective for the silicon diode but also for use with thyristors.

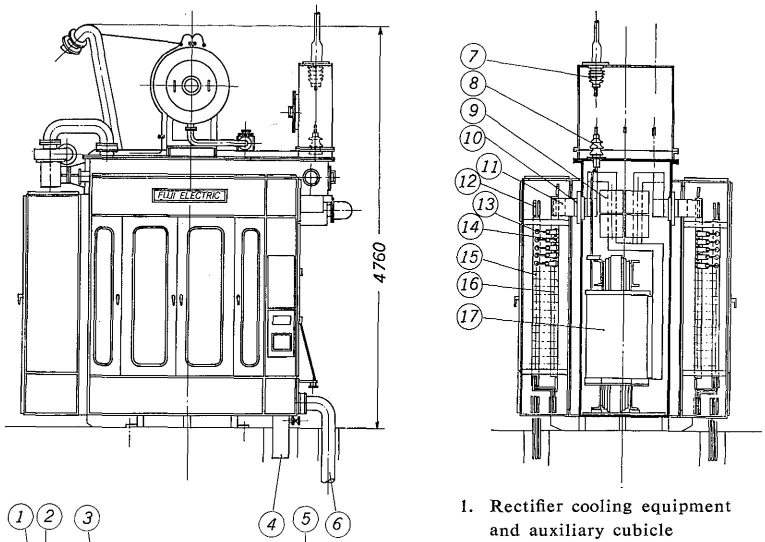
V. INDIRECT TYPE S-FORMER

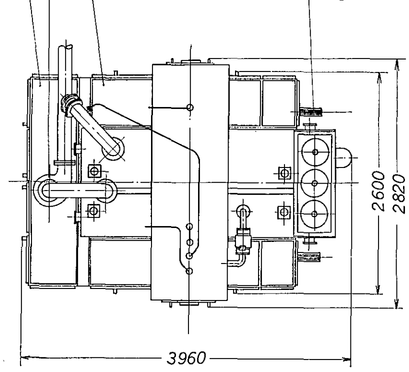
1. Construction

The water cooled silicon rectifier mentioned previously can be made quite compactly even for large current of over several ten thousands amp and therefore it may be easily connected electrically in a short distance from the transformer secondary side terminals. The combined unit of transformer and the rectifier in this manner is called the indirect type S-former. Four representative units are presently under production and bound for the Kambara Plant of Nippon Light Metal. The internal construction and the outside shape of the 8280 kw, 460 v, 18,000 amp unit are shown in *Fig. 11*.

The rectifier is composed of two groups of three phase bridge connections of 9,000 amp and each group installed at either side of the transformer tank and connected to the secondary windings of star or delta connections, then the rectifying phases is 12 in total. 12-phase voltage control reactors are inserted between the transformer secondary winding and the rectifier. These are built in the same tank as the transformer and control the current automatically. The re-cooling device for the circulating water of the rectifier is of the water-to-water cooled type and is enclosed inside the cubicle which is installed on the other surface of the transformer, being connected to the rectifier with polyethylene hose.

The transformer oil is cooled by a separately installed air cooled type heat exchanger. The rectifier diode protecting fuses inside the rectifier cubicle are identical to the ones of *Fig. 6* of the previous sec-





1. Rectifier cooling equipment and auxiliary cubicle
2. Transformer-use oil circulating pump
3. Silicon rectifier cubicle
4. Dc positive terminal
5. Dc negative terminal
6. Transformer cooler pipings
7. Cable head
8. Ac terminal
9. Voltage control reactor
10. Transformer dc terminal
11. Transformer rectifier connecting lead
12. Rectifier cooling water pipings
13. Silicon rectifier diode
14. Fuse
15. Rectifier diode assembly bus bar
16. Fuse assembly bus bar
17. Transformer core and windings

Fig. 11 **Outline and sectional drawing of dc 460 v 18,000 amp indirect type S-former**

tion. In this case, they are screwed into the water cooled bus bar in the same manner as the rectifier diode, the produced heat being also removed by water. Also, the heat loss of the water cooled conductor created inside the cubicle is removed entirely through the water and special cooling of the air within the cubicle is not necessary.

Of course, these S-formers, excluding the oil conservator, are shipped to the location as assembled in the production plant, so that the cost and time for the work at site is greatly reduced.

Several other large rectifiers are in the midst of design at Fuji Electric.

2. Steps for the Purpose of Further Enlarging the Output

As has been mentioned in the previous paragraphs, the development of water cooled system construction, and furthermore, the expectation of rapid development in the increase of output per unit of diode through the appearance of disk type silicon rectifier diodes which can be cooled from both surfaces, afford limitless end to the unit fundamental output of the S-former through the efforts of new techniques, but there still remain major obstacles of electrical problems.

These are the increase of effective resistance of a conductor which goes with large alternating current, the local heat around the transformer bushing, the increase of local loss of leads inside the transformer tank, the unbalance current distribution between the parallel rectifier paths and the reduction of the combined power factor.

In the case of the electrical furnace installation where similar large ac current is handled, as a step to remove these troubles caused by self inductance of the conductors, either arranging the sending and returning conductors side by side and placing them in a sandwich formation or displacing the three phase conductors symmetrically in close proximity to allow self reactances to cancel each other are the most usual methods.

However, it is extremely difficult to physically place these conductors within the rectifier in such arrangements and the required amount of the conductors will also increase.

Also, no matter how skillfully the three phase conductors are displaced, current flow angle of each phase is 120°C and at any point current flow will be in one phase only so that the cancellation will be void.

As a method to solve this problem, in-phase contra-polarized connection method for cancelling the reactance is planned. (Fuji patented system.)

With respect to the large current transformer, more than one secondary winding being wound in parallel is the normal arrangement. It is also narmal to have more than one bushing for pulling them out.

The three phase half wave connection is chosen as the most simple example, and is shown in *Fig. 12.* The secondary windings are brought out in such a close proximity to each other that the voltage phase will have a 180° difference. Similarly the rectifiers are connected with opposite polarity to each of these so that the reverse current will be passed through them at the same time with the result being that each will tend to cancel each other's reactance. By this method, the trouble mentioned previously will

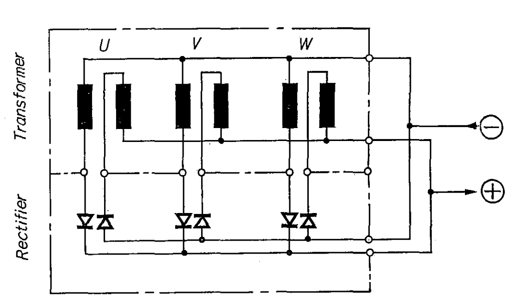


Fig 12 **Connection diagram of in-phase contra-polarity method**

Table 3 **Manufacture List of Direct Type S-former**

Destination	Ac Side		Dc Side			Connection		Cooling Water Quantity	Diode	Location	Internal Apparatus					
	Voltage (kv)	Frequency (cps)	Voltage (v)	Current (amp)	Output (kw)	Ac side	Dc side	(l/min)			I.P.R	V.C.R	S.TR	Tap Sw.	人, △ Sw.	— —, # Sw.
Kanto Electro-Chemical Co.	10.5	50	120	33,000	3960	人	2×人Y	120	Si 150	Indoor	○			○		○
Yawata Iron and Steel Co.	3.3	60	39	15,400	600	△—人	人Y	60	Si 250-1	Indoor	○			○	○	
Hokkaido Sada Co.	22	50	230	24,000	5520	人	人Y	150	Si 250-3	Indoor	○	○	○	◎		
Dowa Mining Co.	6.4~3.2	50/60	300	20,000	6000	人	人Y	150	Si 250-3	Indoor	○	○	○	◎		
Sumitomo Metal Industries	11	60	220	6000	1320	△—	人Y	Air-cooled	Si 250-3	Indoor	○	○	○	◎	○	
Copper Refineries Pty. Ltd (Australia)	11	50	120	16,000	1920	△	人Y	Air-cooled	Si 250-3	Outdoor	○	○	○	◎		

I. P. R. : Interphase reactor V. C. R. : Voltage control saturable reactor S. TR. : Series transformer Tap Sw : Tap changer
◎ mark indicates on-load tap changer.

be removed and at the same time, the result may be created to balance the apportioned current automatically by means of mutual reactance between the two groups of rectifier circuit intermodulation having opposite polarity.

As a result of the above, it is no longer a problem today to construct economically an S-former with more than 100 ka of unit base.

VI. DEVELOPMENT OF DIRECT TYPE S-FORMER

As previously stated, this type is the result of literally combining a transformer and a rectifier into one compact unit. The only cooling device necessary is the type which uses oil cooling and can be considered as the most handy rectifier.

The very first such equipment were the two units of 120 v, 33,000 amp which were delivered to Shibukawa Plant of Kanto Electro-Chemical in 1963[3]. Since that time, advanced techniques which will be mentioned later, were applied and various applications with electrolysis services of medium capacity of several thousand kw as the mainstay were activated to display its true value.

The No. 1 unit was not equipped with any other regulating device than the no-voltage tap changer as dc booster which is connected in series with the existing silicon rectifier. However, these were furnished to the subsequent units.

The principal new techniques are as follows:

1) Through the use of a pressure contact type diode with higher permissible operating temperature instead of the soldering type diode mentioned in Chaper IV, matching of the design conditions of the temperatures for the transformer and the rectifier was planned.

2) The on-load tap changer as well as the voltage control reactor were furnished to the subsequent units which followed the one delivered to Hokkaido Soda Co. (*Fig. 13*). This technique can be applied as is to the indirect type S-former which was mentioned previously.

Many new ideas are being devoted to the purpose of enclosing the voltage control reactor compactly inside the transformer tank.

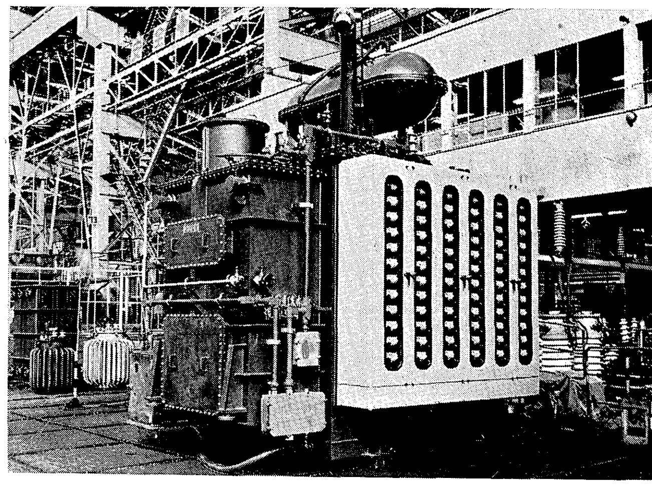


Fig. 13 Outer view of dc 230 v 24,000 amp direct type S-former with on-load tap changer

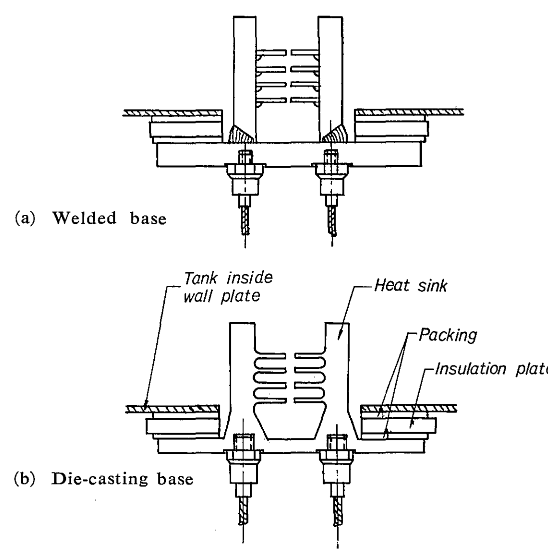


Fig. 14 Sectional drawing of diode fitting base

3) The fitting base plate of the silicon rectifier diode, as shown in *Fig. 14,* were changed from welding construction of oil cooled heat sinks to die-casting with heat sinks resulting in a rise in cooling effectiveness and lowering of production cost.

Through concentrated efforts using these techniques, those apt to raise unit cost with the capacity

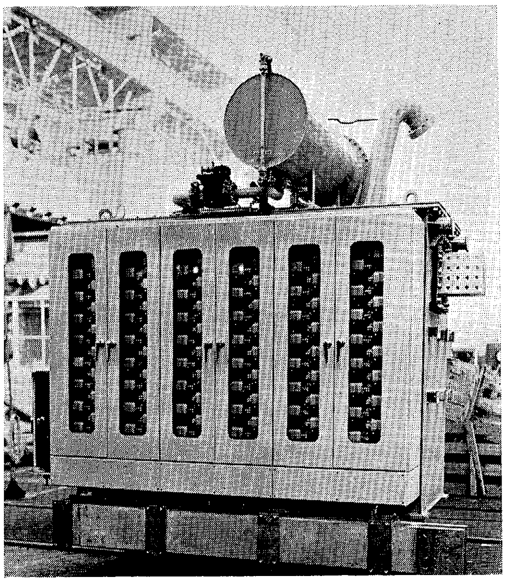


Fig. 15 Outer view of dc 39 v 15,400 amp direct type S-former

small (600 kw) in proportion to the current (15,400 amp) because of the low voltage (39 v) as in the case of special heating power supply-use S-former which was delivered to Yawata Iron & Steel Co. (*Fig. 15*), were able to be completed realistically. Furthermore, the economical production of large capacity of several ten thousands of amperes was possible. Making use of the advantages of the direct connection type, this system is being used for the production presently under way not only for domestic use, but also for the first Australia-bound silicon rectifier equipment.

VII. CONCLUSION

More convenient and economical rectifier equipment has been completed through the appearance of new silicon rectifier diodes, development of realistic cooling systems and advancement of design and production techniques of voltage control reactors as well as the transformers which are combined with the rectifiers, the practical unit base output being almost limitless.

Furthermore, in order to accompany the direct step-down from the power receiving line with over 60 kv, a realistic power factor improved system[7] and load opening and closing by tertiary circuit system (we call tertiary cut), unique to this company, which also allow the rectifier-use transformer as general power usage, are applied. It may be said that large capacity electrolysis equipment will enter a new epoch in this respect.

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