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SILICON TRANSFORM-RECTIFIER

By Shoichi Hattori
Toshihiko Ito
Chiba Factory
and
Masao Nakano
Power & Industry Technical Dept.

I. PREFACE

The silicon transform-rectifier (to be hereafter called S-former for short) consisting of a transformer and a silicon rectifier has recently come to the fore, particularly in conjunction with rectifying facilities for electrolysis. We delivered the first of its kind to Shibukawa Plant of Kanto Denka Kogyo K.K. which went into actual operation early in March 1964.

We would, therefore, like to take advantage of this column to speak about the S-former in general.

Advantages of the S-former may be summarized as:

(1) Smallness of space for installation
(2) Improvement of efficiency and power factor over the conventional equipment
(3) Shorter period required for installation

These advantages all derive from the fact that the connecting conductor may be shorter. In this respect, our transform-rectifier is different from the conventional equivalent; it may be termed as a full-fledged transform-rectifier with a silicon rectifier element directly fitted to the terminal of the transformer as will be explained later.

As for the improvement of efficiency and power factor.

1) Efficiency

According to the standard (JEM 1156) conductor loss (bus bar) is not counted as stipulated efficiency but from the standpoint of the user the conductor loss should invariably be reckoned with. The conductor loss may be calculated from a simple formula as below per 1 ton at the normal temperature of 20°C.

(1) When copper is used: $W=2\times A^2$
(2) When aluminum is used: $W=10.5\times A^2$
W signifies loss per 1 ton of conductor (kw)
A signifies current density (amp/mm^2)

2) Power factor

Conditions to determine power factor are:

(1) Per cent reactance of the transformer
(2) Reactance of the secondary side conductor of the transformer
(3) Reactance had by voltage regulating reactor

The conductor reactance in (2), in particular, is in direct proportion to the conductor length as shown in the following equation:

$L=2l\times(l_n\ d/r_g+0.25)\times 10^{-9}$

L: Inductance (in Henry)
l: Length of conductor (in cm)
d: Distance between two commutating conductors (in cm)
r_g: Constant according to shape of conductor

The construction arrived at by our company from the above considerations calls for shorter conductor for the ac on the lower voltage side, which presupposes a significant improvement in efficiency and power factor.

II. OUTLINE OF 1ST S-FORMER EQUIPMENT

The construction of the S-former delivered to Kanto Denka Kogyo K.K. will be stated later; its characteristics in specifications, however, are:

1. 12-phase Rectification

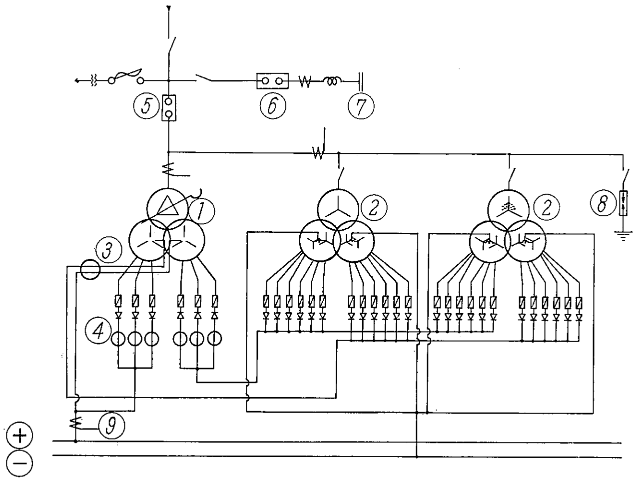
The equipment delivered consists of two sets, each having the capacity of dc 120 v 33 ka and connected in a series to the existing silicon rectifier set (dc 120 v 66 ka) on the d-c side as shown in *Fig. 1*, making an overall set up of dc 240 v 66 ka. Such a high capacity as this as the source of electrolysis necessarily entails faults due to high harmonics. Since the ac winding of the existing rectifier transformer is of delta connection, the ac winding of this S-former is of star connection and there is, in totality, 12-phase rectification as viewed from the electric source.

2. Absence of Voltage Regulator

Voltage regulation is taken care of by the on-load tap changer and the voltage regulating reactor of the existing rectifying device. The transform-rectifier aims at raising voltage to the constant figure of 120 v and there is a crude four-step tap which changes over at the time when no voltage is applied.

3. Small Space for Installation

There is extreme economy in the space required



① Existing silicon rectifying equipment
② S-former
③ Interphase reactor
④ Voltage regulating reactor
⑤ Breaker
⑥ Condenser switch
⑦ Condenser
⑧ Arrester
⑨ Dc current transformer

Fig. 1 Skeleton diagram of Fuji S-former for Kanto Denka Kogyo K.K.

for its installation with all its capacity maintained at the same value as for the conventional counterpart. The whole thing is reduced to about one fifth.

4. Simplification of Allied Apparatus

Instruments, relays, etc. necessary for maintenance purposes are greatly simplified; a water flow relay, oil flow relay and a dial thermometer are all the apparatus fitted. The silicon rectifier, per se, does not require any protective device excepting high

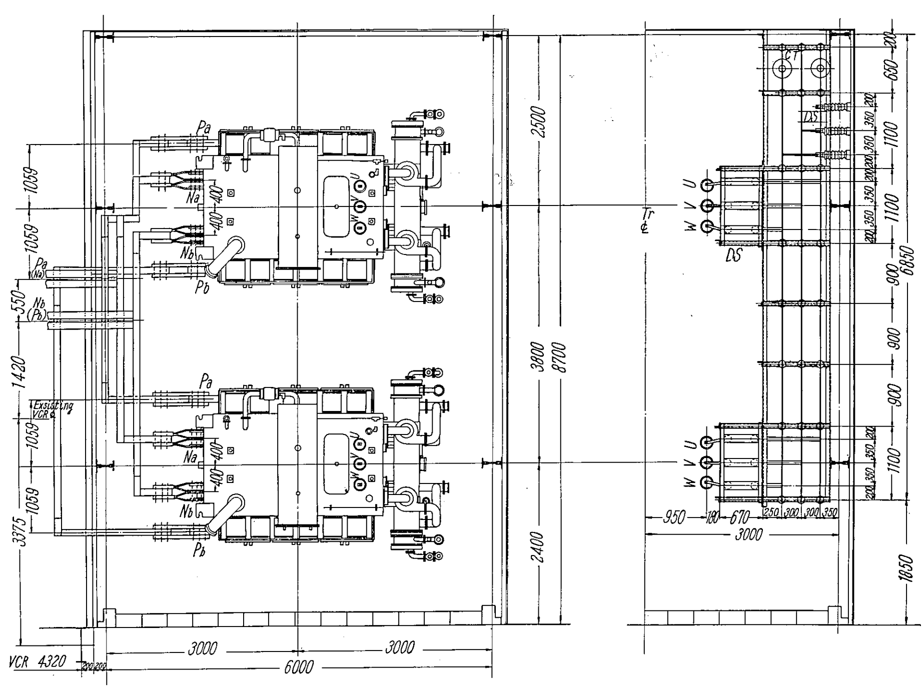


Fig. 2 Arrangement of Fuji S-former (No. 1)

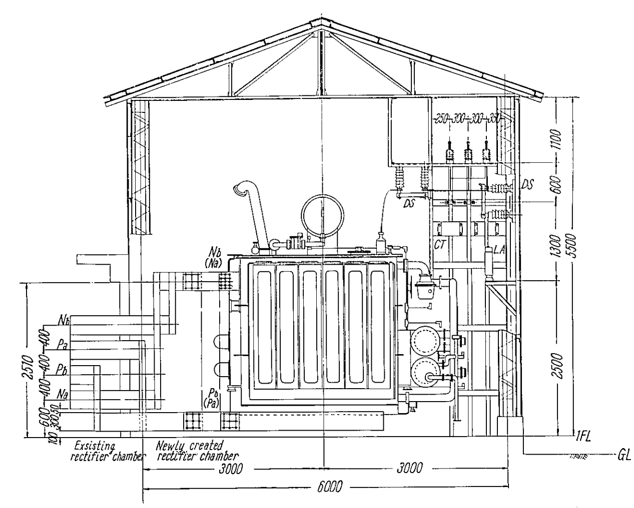


Fig. 3 Arrangement of Fuji S-former (No. 2)

speed fuse. It thus makes maintenance and inspection very simple.

III. RATINGS AND SPECIFICATIONS

1. Specifications

Indoor use, oil (Fuji Nox insulation oil) immersed, forced oil circulation water cooled, provided with interphase reactor.

Phase: 3, rated frequency: 50 c/s, rated output: 3960 kw, rated ac voltage: 10,500 v, rated dc voltage: 120 v, rated dc current: 33,000 amp, ratings: A_0 (100% continuous rating)

1) Ratings of transformer

Connection: Star connection on a-c side, $2\times$double star connection on d-c side

Rated capacity:
A-c side, 4800 kva;
d-c side, $2\times 2\times 1700$ kva

D-c side voltage:
R 119–90.6–59.5–45.3 v

2) Rating of interphase reactor:
Conductor through-type rated voltage: 30 v

3) Rating of silicon rectifier

Composition:
Series 1, parallel 44, phase 6

Silicon rectifier element model: Si 150

Number used: 264

Model of protecting fuse for rectifier element:
RF 1233 f-350

Parallel condenser: 1 μF

Condenser series resistance: 40 Ω 5 w

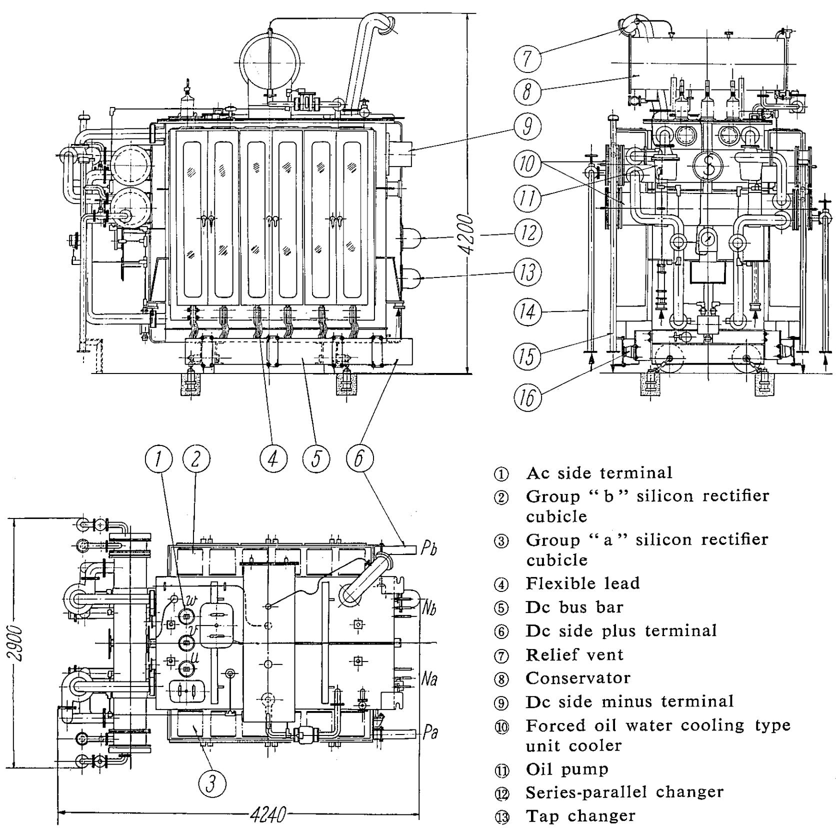


Fig. 4 Outline drawing of Fuji S-former

① Ac side terminal
② Group "b" silicon rectifier cubicle
③ Group "a" silicon rectifier cubicle
④ Flexible lead
⑤ Dc bus bar
⑥ Dc side plus terminal
⑦ Relief vent
⑧ Conservator
⑨ Dc side minus terminal
⑩ Forced oil water cooling type unit cooler
⑪ Oil pump
⑫ Series-parallel changer
⑬ Tap changer
⑭ Water inlet piping
⑮ Water outlet piping
⑯ Dc bus bar holding insulator

2. Specifications

Circulating oil:	2400 *l*/min
Cooling water:	120 *l*/min at water temperature of 25°C
Total weight (include oil):	24,000 kg
Content weight:	10,000 kg
Oil quantity:	7300 *l*
Exterior dimensions:	See *Fig. 4*
Total loss (measured value):	148.8 kw at 75°C
Stipulated efficiency:	96.4%
Auxiliary loss (measured value):	7.18 kw
Voltage regulation (measured value):	7.35%
Temperature rise (measured value):	Insulation oil 30°C Ac winding 43°C

IV. CONSTRUCTION

1. Determination of Basic Type

The ultimate of a transform-rectifier would be a type which contains rectifier elements in a transformer tank. In fact, with selenium rectifiers there are many in which both the transformer and the rectifier are housed in a common tank, and the concept of a transform-rectifier is itself by no means novel. Reasons why this was not realized when the silicon rectifier made its debut are that the state of the element losing rectifying function is mutually contradictory, that the silicon element had very poor reliability and that its construction would have been inappropriate to oil cooling. When the silicon element loses the rectifying functions, short-circuit takes place, and in order to prevent the effect of faults fuses are inserted in a series per each element and they are, of necessity, assembled in independent cubicles to facilitate element replacement.

However, it is beyond any doubt that a transform-rectifier with the elements thoroughly immersed in oil will make its debut in view of the fact that the quality and performance of the product have improved and the past record accumulated, by virtue of a success with the oil-immersed construction of silicon rectifier elements.

It would have been easier if it had simply been the matter of fitting the conventional silicon rectifier to the transformer tank to unite them. However, then there would have been no integration of the cooling systems and no economy of space would have been realized. The principal aim in determining the basic type was to approach it to the ultimate of a transform-rectifier as much as possible, by having the element outside the tank but by placing the rear surface of the base accommodating the elements inside the tank to cool it with the same insulating oil as the transformer. Since the cooling medium is oil, ten times as much effect as air is obtained for cooling, and, what is more, the problem of corrosion and scale accumulation is eliminated which would otherwise be associated with water-cooling. The temperature control of both transformer and rectifier is unified and, although the cubicle to surround the rectifier is necessary, its size may be half the conventional size and the transformer tank does not have to be so big, nearing the ideal style.

2. Problems in Design

Our rich experience in designing and manufacturing rectifier transformers warrants optimism in the construction of the transformer part of the present equipment. In fact, it is proven that, as a result of tests, reactance and stray load loss are small and that there is no local heating of constituent parts such as the tank, for example, and the current in each phase group is well balanced.

To economize the cost of materials, an aluminum plate is used as the element taking base and excepting the conductor of the ac bushing and the tap changer contact, all electric conducting materials such as winding, lead and terminal are of aluminum. Induced voltage per turn is held relatively low and the relative weight of lead against winding is big. In a transformer for a rectifier such as this, it would be more advantageous to cut down on the cost of conductors than to reduce current density. The oxidizing phenomenon by insulating oil with copper is eliminated and the insertion of nitrogen gas in the conservator is not necessarily required. Our conservator being open is based on this observation. To be absolutely sure, insulating oil with Fuji Nox (oxidizing preventive) is employed. Various problems connected with the use of aluminum have been carefully studied and weighed and are all settled and there is no room for misgiving in this respect.

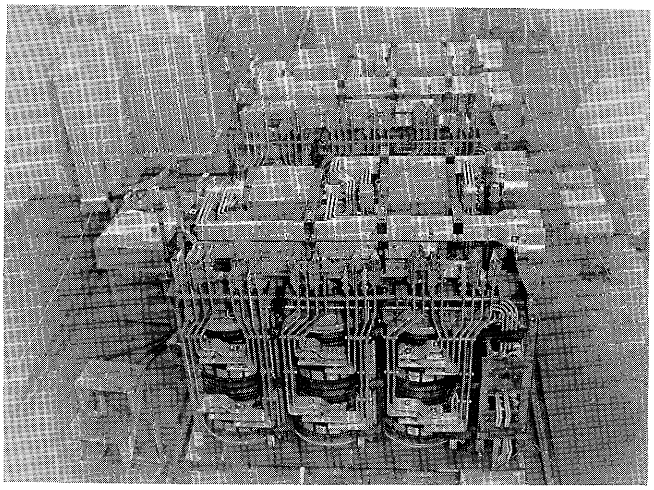
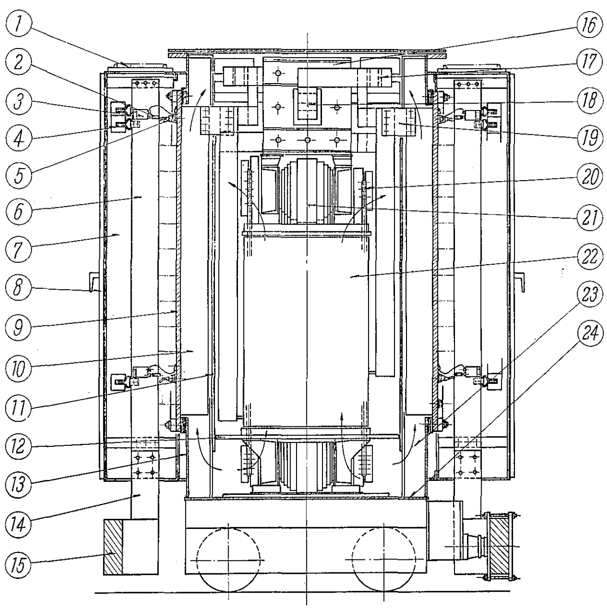


Fig. 5 External view of transformer core and winding of Fuji S-former



① Air outlet gallery
② Element protecting resistance
③ Element protecting condenser
④ Super rapid fuse
⑤ Silicon rectifier element
⑥ Collector
⑦ Silicon rectifier cubicle
⑧ Door
⑨ Silicon rectifier element fitting base
⑩ Cooling fin
⑪ Oil guide
⑫ Oil guide
⑬ Tank side plate
⑭ Flexible lead
⑮ Dc plus bus bar
⑯ Interphase reactor
⑰ Dc minus bus bar
⑱ Interphase reactor penetrating conductor
⑲ Flexible lead
⑳ Ac side lead
㉑ Core
㉒ Winding
㉓ Oil flow
㉔ Tank base plate

Fig. 6 Sectional drawing of Fuji S-former

Some of the items that were emphasized, among other things, in designing the present equipment were as follows:

1) To prevent deterioration of insulator between element fitting base and tank
2) Oil tight construction of element fitting base
3) Cooling of element
4) Uniformity of current distribution among parallel elements

Concrete solutions to these issues will be dealt with later, but, briefly, No. 1 has been solved by using phenol resin laminations which can withstand high temperature oil and also hard vinyl chloride plate and ceramics that withstand acid. No. 2 has been solved by selecting materials, improving size accuracy, providing ampler allowance for packing and by maintaining proper rate of compression. For better cooling of the elements, element and base are fitted perfectly tight and a fin with ample radiating space is fitted to the rear of the base. Tests showed that the oil temperature rise may be allowed up to a still higher degree. As for the current distribution of each element, unbalance has been held down to values well within the tolerance by proper location of conductors and by proper selection of section area.

3. Transformer and Interphase Reactor

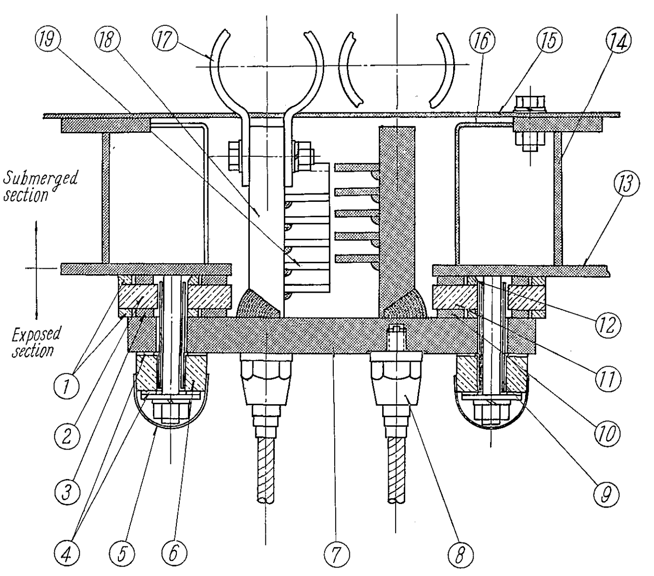
The winding is sandwitch type construction. The a-c side winding may be varied in four steps of V/T by changing series to parallel and by tap changer to meet the conditions of electrolysis cell of the dc voltage. This is further divided into four groups and both groups are perfectly balanced on the dc winding side constituting groups a and b of double star connection. The combination is also such that magnetic coupling is small. For this reason, axial mechanical force by short-circuit is very small. The series-parallel changer and the tap changer provided at the side of the winding are controlled on the floor by a handwheel. The dc winding lead is divided into both sides of the winding for each of the groups a and b, and is located in a firm and compact manner. The interphase reactor is also divided into two sets to make the tank small and to prevent the groups a and b from combining.

4. Fitting Base of Silicon Rectifier Element

For one phase 24 elements can be fitted in two rows each of 12 steps, of which 22 are used and the two excessive ones are fitted with blind plugs. The base and the fin are made of aluminum plate corresponding to class 1 of JIS, which are made monobloc by welding. Due caution was paid in welding them to make heat conductivity good and to avoid distortion from arising.

1) Base insulation

In addition to withstanding insulation of class No. 1 of insulation, this insulation must not deteriorate through many years of operation as it has also to do with oil tightness. Since the present equipment is used for electrolysis of brine, the insulator has to cope with chlorine gas leaking from the electrolytic tank and also chlorine hydrogen generated in combination with water. The insulating frame is put in between the tank and the base and fastened with a packing fitted to both sides, so that bend of a certain degree is required, and the use of resin plates is necessitated. The inside of the frame is exposed to oil of high temperature, while the exterior is subjected to chloride hydrogen. Phenol resin or epoxy resin which withstands high temperature and which is free from the possibility of creeping is, more or less, affected by acid and presents a certain amount of concern for use over an extended period of time. On the other hand, thermoplastic resins such as vinyl chloride are not affected by acid but still are unsuitable for use under pressurized conditions at high temperature. Consequently, the present equipment uses different materials for the interior and the exterior of the insulating frame, so that the characteristics of both materials may be fully utilized. For air tightness between the inner frame and the outer frame, the nut and the washer are provided with an air tightening paint on the surface and a seal cap with adhesive inside is placed over the insulator base for perfection.



① Stopper (Hard vinyl chloride)
② Outside insulating frame (Hard vinyl chloride)
③ Packing (Neoprane rubber)
④ Cushion (Neoprane rubber)
⑤ Seal cap (Hard vinyl chloride)
⑥ Insulating washer (Ceramics)
⑦ Base (Aluminum plate)
⑧ Silicon rectifier elements
⑨ Insulating tube (Polyproperane)
⑩ Packing (Nitril rubber)
⑪ Internal insulating frame (Phenol resin lamination)
⑫ Stopper (Phenol resin lamination)
⑬ Tank side wall (Steel plate)
⑭ Tank reinforcement (Steel plate)
⑮ Oil guide (Press board)
⑯ Oil guide (Steel plate)
⑰ Flexible lead (Aluminum plate lamination)
⑱ Main cooling fin (Aluminum)
⑲ Auxiliary cooling fin (Aluminum plate)

Fig. 7 Sectional drawing of fitting parts of silicon rectifier element

2) Oil tightening construction of base

The screw hole for the screwing of the silicon rectifier element is within the thickness of the base so that it will not depend upon the oil tightness of the fin welding part. There is, therefore, no possibility of oil leakage from the screw holes. With a construction such as this, the oil tightening packing between the base and the tank tends to be long so that enough precaution needs to be exercised in designing the oil tightening section. Severe reception tests were given to both the material of the packing and to size accuracy. Size tolerances also tend to grow and the packing surface also becomes large to eliminate waving. Sufficient allowance for tightening or fastening is taken by making the packing thicker.

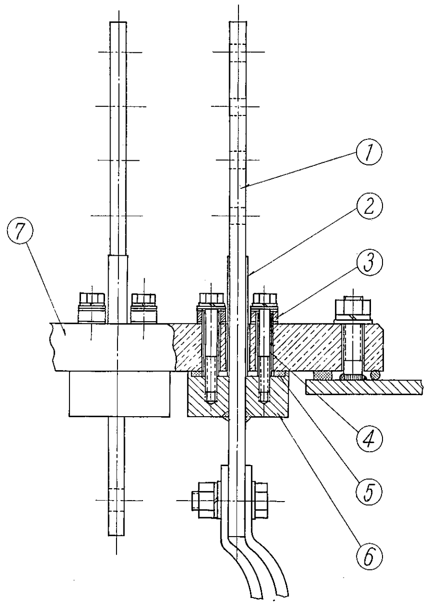
5. Flat Bar Terminal of Dc Minus Pole

A flat bar terminal suitable for low voltage high current is used as the bushing of the tank penetrating section of the dc minus bus bar. The insulating plate for partitioning is of phenol resin lamination but the bar is furnished with a sleeve of hard vinyl chloride and the bolt which fixes the bar to the partitioning board is separated from the partitioning board by a ceramic washer and a vinyl chloride insulating tube, so that the electrically charged section will not directly touch the phenol resin in the atmosphere.

6. Rectifier Cubicle and Dc Bus Bar

At the front is a door that opens to the left and right direction with a window fitted with organic glass. Although it is fitted to the side of the tank, air is made to circulate naturally from an opening below to the ventilating gallery up above so that no heat may accumulate inside. When it is used in a particularly bad atmosphere, a closed circulating ventilation would be necessary, in which case an air tight construction would be required with bolts fastening it securely and the expiration would have to be done by means of the absorbent of humus gas.

The dc bus bar is arranged below the cubicle



① Terminal bar (Aluminum plate)
② Insulating sleeve (Hard vinyl chloride)
③ Insulating washer (Ceramics)
④ Insulating tube (Hard vinyl chlorid)
⑤ Packing (Nitril rubber)
⑥ Flange (Aluminum plate)
⑦ Partition board (Phenol resin lamination)

Fig. 8 Construction of flat-bar type terminal

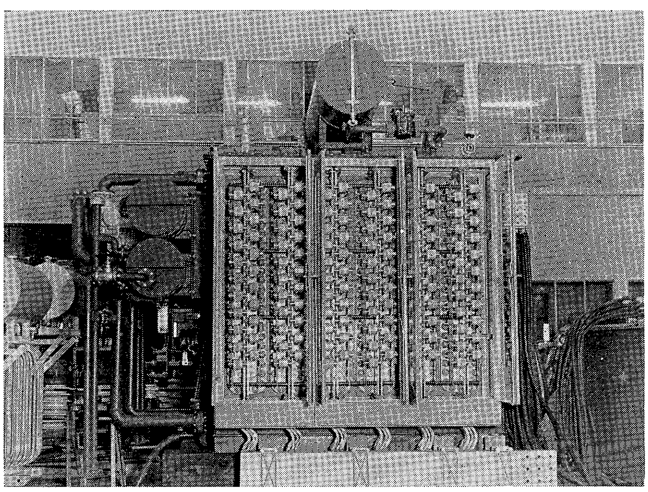


Fig. 9 External view of Fuji S-former

and the collecting bus inside the cubicle is connected by a flexible lead. The dc bus bar is of aluminum ingot, which is held down to about 0.55 amp/mm^2 current density.

7. Cooling

The continuous temperature permitted at the junction of the silicon rectifier element is 140°C and it may appear that cooling is easier than the transformer. However, the route leading from the junction to the cooling fin is long and complicated and heat flow density is very high. Consequently, a big temperature fall is required until the heat flow reaches the surface of the cooling fin and the temperature of oil is restricted not by the cooling of the transformer but by the cooling of the elements. Sometimes, it may not be wise to cool the elements with the same insulating oil common to the transformer. In other words, in case where a big capacity is being talked about and there is no cooling water available and air cooling is the only alternative, there is advantage in separated cooling systems. There is usually a difference of 15°C between water and air which are both indirect cooling agents of the elements, and since the temperature of oil, which is a direct cooling agent, has to be kept at a constant value, air would be a difficult element for cooling. As the loss of the silicon rectifier element would be 20 to 30% of the total loss, this difficulty could be lessened when the element and the transformer are separated.

As cooling water is available for this, it is easy to cool both simultaneously, and with the capacity being what it is, the cost will not be diminished if they are separated but, instead, will increase costs outside the field of cooling device and will make maintenance and handling difficult. It would be wise, therefore, to cool them both at the same time. Two sets of forced oil water-cooling type cooler are mounted on the tanks, and the oil that is cooled is sent to the lower tank. In the tank is an oil guide which controls the flow of oil to the transformer and to the element fitting base fin section in the most appropriate manner. As long as the fin thickness is set at a fixed value, heat conductivity by the fin is limited by its altitude and so a thickness in harmony with the amount of heat to be conducted should be selected.

In order to keep the minimum temperature difference between the base and the element case it is important that the flanged surface of the case and the countersunk part of the screw should be perfectly tight. The temperature test on dc 10.4 v, 33,000 amp showed that the difference in temperature between the base and the case is unexpectedly low. The relative case temperature rise in relation to temperature registered 32°C at maximum on the part of the element. Oil temperature rise may, therefore, be tolerated up to a higher degree.

V. ADAPTATION OF TRANSFORM-RECTIFIER

1. Voltage Regulation

Our first S-former does not have its own load voltage regulator as already described. However, when a transform-rectifier is set up and operated independently, voltage regulator is invariably required for the following reasons:

1) To regulate electrolytic current by reason of production administration;

2) To keep electrolytic current constant by compensating for fluctuation of voltage at electric source or mains;

3) To keep electrolytic current constant even when the number of electrolysis cell changes (when there is trouble in the cell or when it needs repair, in case of curtailed operation or when completed cell are to be put in the system one after another).

4) To compensate for changes in the state of the electrolysis cell and to keep electrolytic current constant (brine electrolysis, water electrolysis, solution temperature, density, interpolar distance, etc. or anode effect when aluminum electrolysis is attempted).

5) To control starting current of the electrolysis cell (according to the kind of cell there is no analyzing voltage at the starting time and this is gradually generated. When the disposal of exhaust gas at the time of starting is considered, the starting current should be controlled).

Against these demands, the following systems may be resorted to in the case of the transform-rectifier just as in the case of the conventional rectifying facilities:

1) A-c side tap changing of the transformer

The transformer for the rectifier for electrolysis has big dc current so that voltage regulation is almost always done by a-c side tap changing. By the nature in operation, most of the on load tap changer is employed.

When the a-c side of the transformer has tap, the upper limit of the tap winding is 160∼170%, so that the lower limit on the dc voltage is about 60%.

2) Tap changing by tertiary winding of transformer

Cell for NaC1 electrolysis have become of large capacity in recent years and 8 to 10 cell are installed to start with, to be gradually increased finally reaching the number of cell corresponding to the maximum voltage obtained by a silicon rectifying element in a series (since with the double star connection the upper litmit of dc voltage is about 220∼250 v in a series of one rectifier element, the total would be about 48∼56 cell). Consequently, the range of voltage regulation required of dc source is becoming wide of late.

In the above-mentioned tap changing system, the voltage regulation range is limited, so sometimes an indirect tap changing by tertiary winding is used. This means a setting up of a main transformer and a series transformer and to regulate the primary voltage of the series transformer by the tertiary winding tap. With a phase changer is used in addition, voltage regulation of 0 to 100% may be possible. However, with the transform-rectifier, two sides of a transformer tank are required for fitting the silicon rectifier element, so that the terminal needs to be drawn to both sides of the tank. When a voltage regulating reactor is housed in the same tank, as stated later, the routing of a low voltage lead would be very difficult and its handling calls for careful attention.

3) Location of voltage regulating transformer

When the rectifying device is divided into more than two systems, or when a phase shift winding is fitted to the ac winding of the transformer for rectifier, a voltage regulating transformer is used. To regulate voltage under load at a single voltage regulating transformer against multiples of systems of transform-rectifier is not necessary uneconomical as compared with attaching a on-load tap changer to each transform-rectifier, but, instead, may be more economical when one thinks of the possibility to measure dc current on the ac side and thus economize on space.

A voltage regulating transformer may freely select the range of voltage regulation as required, in which case the regulating capacity will be as follows:

$$\text{Total input capacity of transform-rectifier} \times \frac{\text{Regulated voltage of voltage regulator}}{\text{Transform-rectifier primary voltage}}$$

To make the range of voltage regulation narrow is economical.

4) Connection change of ac winding of transform-rectifier

It has been practised in the past also to change the ac winding of the transformer into series-parallel or delta-star but when there is a tap to the ac winding, the general procedure is delta-star changeover. This is done when no voltage is applied either manually or electrically or sometimes by means of six bushings for continuous alteration. For voltage regulation which is not so frequent, this system, and, the voltage regulating transformer mentioned under 3) may be used for small regulating capacity and yet a wide range of voltage regulation.

5) Voltage regulating reactor

The regulating theory of a voltage regulating reactor will not be touched upon here but as a means of complementing continuous regulation of dc voltage obtained in steps by means of a on-load tap changer, this is better economically and speedwise than an induced voltage regulator. When the transformer and the rectifier are separated, this reactor has been made a dry type coming in horizontal or vertical shape according to location. In the case of the transform-rectifier, it is housed inside the transformer tank in the way of shortening the a-c side conductor outside as much as possible. This has been experienced in the early period of the introduction of the silicon rectifier.

2. Examples of Planning

Fig. 10 shows the examples of planning at dc voltage of 250 v and the current of 10, 30 and 50 ka, respectively.

This has a on-load tap changer as its standard accessory and houses a voltage regulating reactor inside, the connection being of double star type. The cooling system is of water cooling but when water is not available it is possible to turn on wind or air-cooling.

The example given here ends with the upper limit of 50 ka, of which the reason follows:

When the electrolysis cell gets of higher capacity, there may be an unbalance in the terminal current of parallels of the electrolysis cell. We have located the conductor impedance from the system of rectifiers to load in an equal manner in our transform-rectifiers as well as big current rectifying devices (100∼150 ka) which we have so far delivered, and have provided automatic constant current adjustment at the unit of 12.5 ka∼25 ka.

If the shortening of conductor may be cited as a feature of the transform-rectifier, we consider it better to directly connect two or three systems near the electrolysis cell jars rather than making a big capacity device in a single system and dragging the conductor. In this case, of course, the transform-rectifier is not provided with a on-load tap changer, and a voltage regulating transformer is offered instead to serve the common purpose. This is more convenient for maintenance and inspection, and at the same time, economical.

3. Merits and Demerits of Transform-Rectifier

There are some who hold that the transform-rectifier is superior in every respect to the conventional counterpart as the source of dc. However, it is not without a single problem.

When the conventional system is taken in which a silicon rectifier and a transformer are separated, it is often possible to increase the voltage of dc output by merely adding a booster transformer to the existing one at the time another electrolysis cell is installed.

This procedure is preferred, more often than not, from the standpoint of saving in the equipment investment.

It is difficult to adopt this step as far as a transform-rectifier is concerned, because a transformer and a rectifier are built in one unit.

As stated already, the characteristics of the transform-rectifier such as:

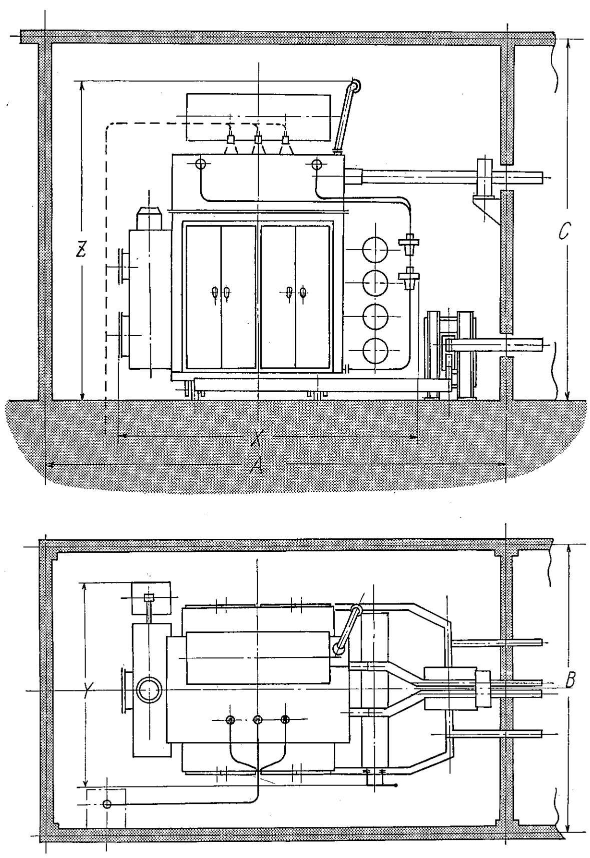
(1) Improvement of efficiency, power factor and voltage regulation
(2) Smallness of space for installation
(3) Simplified installation engineering

may be reiterated. We have already delivered equipment which guarantees the same degree of efficiency, power factor and voltage regulation as the transform-rectifier, even when the transformer and the rectifier are separated, thanks to our unique cubic arrangement, and the equipment has continued to operate satisfactorily. In some cases, the house has the upper floor but the required space does not differ much from the transform-rectifier. Judging from these problems it may be said that preference for either the conventional separate type or the combined transform-rectifier has to depend upon planning of additional facilities, the existing houses, etc.

IV. CONCLUDING REMARKS

The transform-rectifier of our company introduced in this article has been running without any problem. It is our desire to manufacture new rectifying equipment on the basic of this success.

In closing, we want to express deep appreciation to Kanto Denka Kogyo K. K. of their unhesitating manner in which they took the rectifying equipment according to this new system for the first time.



Rated Dc Voltage (v)	Rated Current (amp) (JEM Ao)	Outside Dimensions (mm) X	Y	Z	Total Weight (t)	Required Water Amount (l/min)	House Dimensions (mm) A	B	C
250	10,000	4700	3500	4600	33.0	140	7400	5200	6000
	30,000	5000	3500	5200	48.5	320	7700	5200	6600
	50,000	5300	3700	5800	63.0	425	8000	5400	7200

Fig. 10 Examples of planning on S-former