UDC 621. 357. 1 : 621. 314. 63. 07 : 621. 314. 51

APPLICATION OF THYRISTORS IN ELECTRO-CHEMICAL PLANTS

Masaaki Takahashi

Tatsuo Shimizu

First Industrial Application Engineering Dept.

I. INTRODUCTION

The electrochemical industy manufactures many products by means of electrolysis for which it requires a large amount of dc electric power. This power is generally converted by a converter from ac power to dc and supplied to the electrochemical plant. Silicon rectifiers employing silicon diodes, have a high efficiency and reliability, are easy to manufacture as large scale units and are more economical than former converters. Therefore new rectifier equipment for electrolysis in recent years has almost all been of the silicon type and is now used in a wide range of electrolysis including brine, aluminum, zinc, etc.

Silicon diodes are now being replaced, however, by thyristors (SCR) which are capable of voltage regulation by means of gate control. The application of electrolysis rectifiers extends to many fields. Thyristors are more expensive than silicon diodes, they require gate control equipment and the internal loss is large. However, due to their excellent properties, thyristors have been used for several years in rectifiers for various types of electrolysis including brine.

Fuji Electric has considerable experience in this field having already manufactured and delivered 200 v 330 ka thyristor rectifier equipment which is the largest of its kind in the world. It also employs thyristors widely in other electrolysis applications. This article will describe the fields, features, economy etc. of thyristors used in the electrochemical industry.

II. OUTLINE OF ELECTROCHEMICAL PLANT

Electrolysis equipment requiring a dc power supply can be classified as follows:

1) Aluminum smelter

Aluminum is produced by the electrolysis of alumina in a crystal rock medium. Recently, smelter equipment has become larger. Standard equipment for an annual output of 50,000 tons has a dc power source rectifier of about 100,000 kw. Aluminum smelter consums the most electric power of all the various kinds of electolysis.

2) Brine electrolysis

Brine electrolysis is utilized in the manufacture of caustic soda and chlorine. Previously caustic soda was the most important product, but recently, chlorine demands have risen sharply since it serves as a raw material for chlorine polymers, especially polyvinyl chloride. Large type electrolysis equipment with current of around 300 ka is now in use. The rectifier is also large like that used for aluminum, and uses the most current of all the various kind of electrolysis.

3) Metal electrolysis

Hydrometallurgy is the purification of metals such as copper, zinc, nickel and lead by electrolysis in an aqueous solution. When compared with the two previous types, power consumption is low but in recent years, the scale of the equipment has increased and a special current control during the electrolysis has been developed (Refer to section VI).

4) Miscellaneous

In addition to the above, there is also water electrolysis, the production of hydrogen peroxide and sodium chlorate, the refining of magnesium and the manufacture of metallic sodium. However, when compared with the above mentioned equipment, the amount of new equipment in Japan for these applications is less than 5%.[2] *Table 1* lists the power unit rates (the amount of power needed to produce one product unit) and examples of equipment for typical electrolysis processes.

Table 1 **Power Unit Rate for Electrolysis**

Electrolysis	Power Consumtion Unit	Examples of Recently-Manufactured Rectifier Equipment
Aluminum	16,000~18,000 kwhr/t	Dc 840 v 176 ka 148 Mw
Brine	3300~3400 kwhr/t	Dc 200 v 330 ka 60 Mw
Zinc	3500~4000 kwhr/t	Dc 300 v 20 ka 6 Mw
Electrolytic Copper	340~350 kwhr/t	Dc 175 v 14 ka 2.45 Mw
Water Electrolysis	4~5 kwhr/m^3 (H_2)	Dc 350 v 12 ka 4.2 Mw

III. FEATURES OF DC POWER SOURCE FOR ELECTROLYSIS

It is essential that the rectifiers for all the electrolysis equipment described in section II allow for voltage adjustment. The aim of this is as follows:

1) For adjustment of the cell current

It is necessary to adjust the cell current to some arbitrary value in accordance with the electrolysis cell.

2) To compensate for source voltage variations and hold the cell current constant.

3) Varying the number of electrolysis cells (pots)

To maintain a fixed current when the number of cells is increased or decreased for repairs, checking etc. or when the number of cells (pots) in sequence is increased during starting.

4) To compensate for variations in cell (pot) conditions and to maintain the fixed current (or a fixed amperage).

5) For starting and stopping

To avoid sudden changes in power during starting or load interruption, and to hold down starting inrush currents.

In accordance with these requirements, dc voltage control is required, but when the diode type rectifier is used, the voltage control methods are as follows since the elements themselves are not capable of voltage control.

(1) Rough voltage control using a rectifier transformer or a load tap changer (hereafter referred to as LTC) of a voltage regulator.

(2) Fine control using a saturable core reactor (hereafter referred to as VCR).

Using both of these methods, stepless on-load voltage control is performed.

IV. THYRISTOR APPLICATIONS

There are two main methods for voltage and current control utilizing the control capabilities of thyristors.

1. Application in Thyristor Type Load Tap Changers

Diodes are used in the main rectifier circuit and thyristors are used as the active elements of the LTC of the transformers. This type of equipment is known as a thyristor load tap changer (hereafter referred to as thyristor LTC) and they are now being developed for power use. This LTC is an arcless changer, so theoretically there is no possibility of contact wear and it can therefore be used for frequent changing. If the number of taps is large and the voltage between the taps is small, the VCR can be omitted. This means that transformers (or rectifiers) which formerly contained VCRs can be more compact. Even though the thyristor LTC is more expensive than ordinary LTCs, it is possible to keep the same price for the overall rectifier equipment. The power factor is also better than in the equipment containing an ordinary LTC andVCR. The reliability and technology of the thyristor LTC has been proven. Once it becomes somewhat cheaper, it will no doubt be more widely employed in fields where the thyristor rectifier described next is not applicable.

2. Application in Thyristor Rectifiers

The thyristor rectifier is the same as the previous rectifier except that diodes have been replaced by thyristors. With this system, the dc voltage is regulated directly by means of gate firing angle (α) control. Since the rectiffer itself are capable of voltage regulation, the LTC and VCR of the rectifier transformer (or the on-load voltage regulator transformer) can be ommitted which means that this is much simpler than the old diode system. Therefore, even though the thyristor loss is more and they cost more, a consideration of the equipment as a whole will reveal that this system compares favorably with the diode system, the efficiency is the same or better, and it is possible to utilize the excellent control capabilities of the thyristors. Therefore, this system is ideal for electrolysis equipment and has become quite popular. *Table 2* gives comparisons between diode and thyristor rectifiers.

V. THYRISTOR RECTIFIERS FOR LARGE CAPACITY ELECTROLYSIS

1. Field of Application

In the field of large capacity thyristor rectifier equipment, electrolysis such as that of brine require low voltage, high current equipment while aluminum smelting etc. need higher voltages and greater power. Economy is also an important factor.

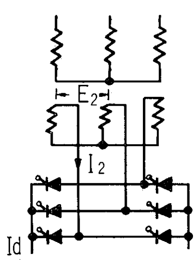
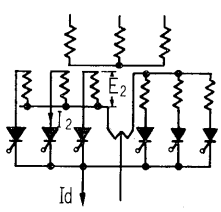
In low voltage high current equipment like that for brine electrolysis, it is best when the ordinary double-star 6-phase rectifier connection is employed. As can be seen from *Table 3*, the secondary capacity of the rectifier transformer is larger than the primary capacity. An interphase reactor is provided and because the windings are complex, it is more expensive than the usual power transformer. The loss is also high when comparing equipment of the same capacity. When the diode system is used, however, the percentage occupied by the cost of the rectifier transformer equipment with the LTC, voltage control winding and VCR in total equipment cost is rather high.

With the thyristor system, the LTC, voltage control winding and VCR in the rectifier transformer can be eliminated. The inner construction is therefore more simple, and the price and loss are reduced. The thyristor rectifier which cost more than the diode system has also become more compact due to the development of a large-current flat-packaged

Table 2 **Comparison Between Thyristor and Diode Converters**

	Thyristor System	Diode System
Voltage Control Method	Voltage control by gate trigger phase control. Control range of 100~0% possible.	Combined rough control by LTC of voltage regulation transformer or rectifier transformer and fine control by VCR. When voltage adjustment range is wide, transformer capacity becomes large.
Control Response	Electronic control by gate pulse. Determined by control circuit time constants, but very fast.	VCR About 0.1~0.3 sec. LTC Tap changing time 4~5 sec.
Control Device	Complex when compared to diode system. Gate control device for each thyristor.	Generally only automatic set current control device provided. Simple.
Rectifier Construction and Cooling System	Enclosed cubicle construction. Cooling by circulating deionized water in the heat sinks attached to thyristors. Deionized water cooled by external water in water-water cooling system.	Same as left. Same af left, but water-air cooling system also possible.
Power Factor	Since source voltage variation compensation component also controlled, several per cent lower than diode at rated operation around 91%. Power factor is low due to voltage control.	About 96% at rated operation. Power factor lowered by VCR control but since wide band voltage control is performed by LTC, power factor decrease can be kept small.
Efficiency	Forward voltage drop of thyristor is about 0.2 to 0.3 v more than diode drop but since transformer tap winding and VCR control are unnecessary, there is no difference in overall efficiency between the two when the rectifier circuit is of the double star 6-phase type.	
Frequency of Voltage Regulation	Appropriate frequency of voltage adjustment. Checking not required because no movable parts.	Frequent tap switching is not used. Control by VCR, but LTC check required.
Equipment Size	Since transformer is compact, installation space is much less than in diode equipment, especially for large capacity devices.	Slightly larger than thyristor equipment.
Max. Temperature	125°C	160°C
Ac harmonic Current	Not only theoretical $n=(kp\pm1)$ order harmonics, but also 5, 7, 11,...23, 25 order harmonics in practice. When voltage control capacity is large, higher order hormonics are in several times.	Same as left. Harmonics do not increase for wide band voltage control by LTC.

Table 3 **Rectifier Transformer Rating and Capacity**

Rectifier Connection		Three-Phase Bridge	Double Star Type 6-Phase
Transformer and Rectifier Connection			
Transformer Capacity	Ac side primary	1.05 P_d	1.05 P_d
	Dc side Secondary	1.05 P_d	1.48 P_d
	Average	1.05 P_d	1.38 P_d *
Dc Winding	Voltage (E_2)	0.74 E_{do}	0.855 E_{do}
	Current (I_2)	0.818 I_d	0.289 I_d

Note: 1. The above values are for commutation angle (μ) and control angle (α)=0
2. * Includes capacity of interphase reactor
3. E_{do}: No-load dc voltage
I_{do}: Rated dc current
$P_d=E_{do}\times I_d$

elements. The control equipment is also reduced so that the price difference is actually very small. Considering everything, the thyristor system is just as economical as the diode system.

Is it also economical to employ the thyristor system in equipment such as aluminum smelting rectifier equipment which has a higher voltage and capacity than the brine electrolysis power source ?

Generally the 3-phase bridge connection is suitable for aluminum smelter rectifier equipment. The windings of the rectifier transformer are as shown in *Table 3*. The capacities are the same on the ac and dc sides. This construction is also simpler than the double star 6-phase connection.

There are many cases when the unit capacity is large and the primary voltage is 11 kv or over (for example, 20 kv, 60 kv or 132 kv), and the construction is almost same with power use. Therefore the percentage occupied by the cost of the transformer in total equipment cost is less than that for the case of double star 6-phase connection and loss is also less. When thyristors are used, the voltage control device and VCR is not necessary for transformer. But the resulting decrease in price is less than in the case of thyristor transformer with double star connection. However, with the thyristor rectifier the number of thyristors used for the 3-phase bridge connection becomes about double that in the former case and gate control equipment must be added so that the price becomes rather high and the percentage of the total price is also high. The total loss is large when compared with the diode system and the cooling system differs with the chemical plant. There are many cases where cooling water can not be used and since forced air cooling must be adopted, and the temperature rise limit of the thyristor is lower than that of the diode, this system is more expensive. From the above points, it seems that the application of thyristor equipment in this field is not advantageous at present because of the high price. Except for a few special cases, no practical experience has been obtain in this field anywhere in the world. From now on, it is thought that thyristors will tend to be employed in thyristor-LTC in this field. The most economical system is one which can perform constant ampere hour control with frequent conversion, has no VCR and has many voltage regulation taps.

2. Thyristor Rectifier for Brine Electrolysis

In recent years, brine electrolysis plants have increased in size to about 300～450 ka and large current equipment is required. Dc power source rectifier equipment for large scale electrolysis plants must fulfill the following conditions:

(1) Must have quick control of electrolysis current in accordance with chlorine requirements. It must also be possible to introduce computer control.

(2) Must be able to handle any cell starting conditions.

(3) When ac power is supplied from both domestic generators or commercial generators (power companies), automatic load control with rapid response in respect to both supply conditions is essential.

(4) Efficiency must be high (high efficiency is desirable even at low voltages).

(5) Installation area must be as small as possible. Must also be possible to install out-of-doors.

(6) Price must be economical.

For brine electrolysis as mentioned in paragraph **1**, the price difference between diode type and thyristor type rectifier equipment is only a few per cent, and there is no difference in efficiency. In respect to

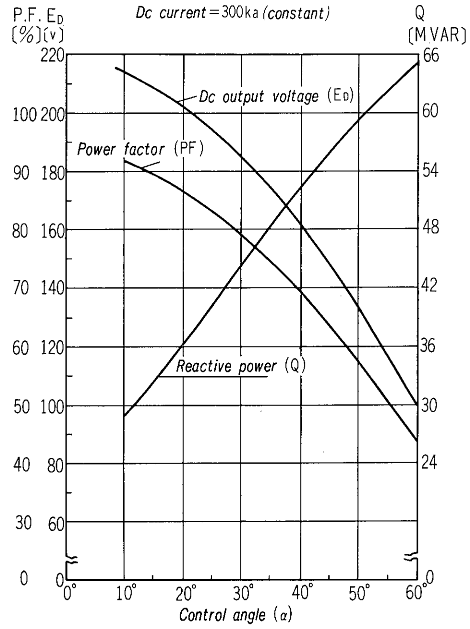


Fig. 1 Characteristics of control angle, output voltage and power factor

conditions (1)～(3), the thyristor system is much superior and for this reason, these systems are becoming much more popular.

When the thyristor system is applicable, the following points must be noted when considering differences with the diode system.

1) Power factor

The thyristor system differs from the diode system in that the power factor decreases in accordance with the voltage control. When there are only a few electrolysis cell operating, control is only for low voltages, but since the rated current flows, the reactive power is extremely high. *Fig. 1* shows a typical example of the relation between the reactive power, power factor, dc voltage, and control angle α when the dc voltage is controlled between 50 and 100% by control α. The electrolysis current is constant at 300 ka.

In order to improve this low power factor, it is necessary to provide a capacitor. This capacitance is never small. Depending on the conditions, no-voltage taps are provided in the transformer or the primary connection is converted from Δ to ⅄ which allows for decreasing of the capacitor magnitude. However, Fuji Electric developed a special connection method for the 200 v 330 ka thyristor rectifier equipment delivered to the Kureha Chemical Co., Ltd. With this system, it is possible to maintain a high power factor and efficiency even at low voltages.

2) High harmonic influence

The harmonic current which occurs in thyristor rectifier equipment is larger than that in the diode system. It is essential to investigate the high harmonics which occur during the operation schedule and select the rectification numbers so that these harmonics do

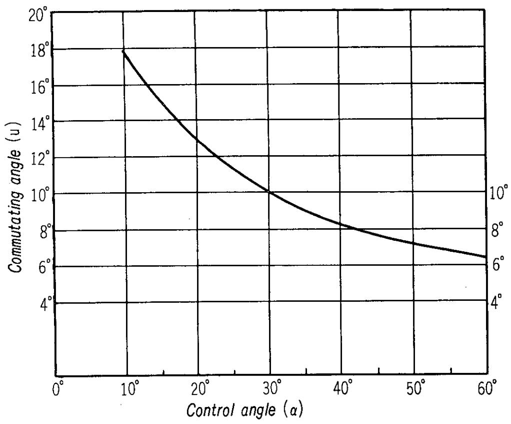


Fig. 2 Relation between control angle and commutating angle

not exert any adverse influence to the power source and the various power loads connected in parallel with it. When the dc current form is completely smooth and there is no overlap of the anode currents, the ac side currents are collected in the form of a square wave. When the rectification number is represented by "p", $n=(kp \pm 1)$ and the magnitude of all harmonic included in the fundamental current is $1/n$. In practice, the lap angle is (u) and there is a slight difference among individual units. Because of these, the amount and degree of high harmonics is altered and it has been confirmed that harmonics of the 5, 7, 11.... orders are present no matter what the rectification number. The lap angle (u) decreases according to control angle α increasing even if the load current is constant as shown in *Fig. 2*, care must be taken since "u" becomes small and the amount of harmonics included increases unlike in the diode system.

When the diode system is used, the control capacity of the VCR is generally small, the problem of differences occurring in the rated output is common. Special attention must also be paid to the harmonic voltage of the ac power source which effects control.

3. Thyristor Elements Applicable

Large current rectifiers for brine electrolysis employ the high-efficiency large-current flat-packaged type KGP01 thyristors (see *Fig. 3*). The cooling system consists of heat sinks arranged on both surfaces of the elements with deionized water circulating through them. With this system, heat losses are eliminated and the cooling effect is high.

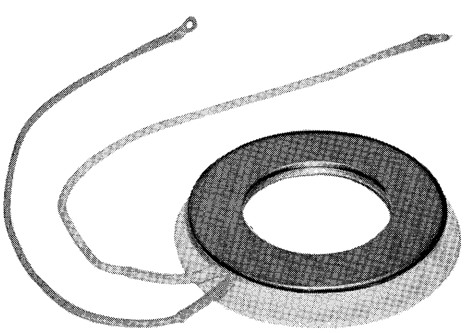


Fig. 3 Flat packaged type power thyristor KGP01

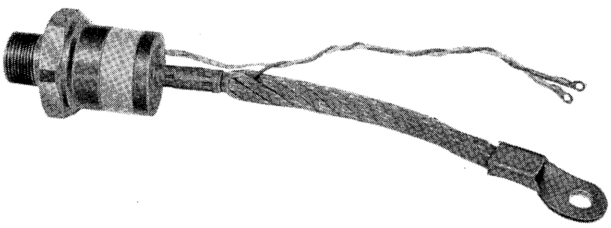


Fig. 4 Stud-type power thyristor GTN01

For middle capacity rectifiers or those in which the output rating current is comparatively low, stud-type GTN01 thyristors (see *Fig. 4*) are used. The cooling system consists of the busses screwed with the elements and deionized water are ciculated in these busses. This cooling system is a standard type which was previously introduced in this issue. The characteristics of the KGP01 and GTN01 thyristors are shown in *Table 4*.

4. Examples of Equipment Manufactured

A typical example of large capacity thyristor rectifier equipment (over 1000 kw) is shown in *Table 5*. *Fig. 5* is an external view of the 200 v 330 ka thyristor rectifier equipment (outdoor type) delivered to the Kureha Chemical Co., Ltd.

To prevent harmonics, the equipment is divided into 3 units (each of 110 ka) and the rectification is then 18-phase. Superior technology such as a device to increase the efficiency by means of a series-parallel changing method (patent applied for), a method to eliminate local heat by means of an in-phase contra-polarity connection (Pat. No. 476880), measures to lower reactance and simplification of the main circuit connections have been incorporated. *Fig. 6* shows a skeleton diagram of this equipment. The main control system consists of a current regulator, a gate pulse generator, a pulse amplifier and a total current regulator. Gate trigger missing and other

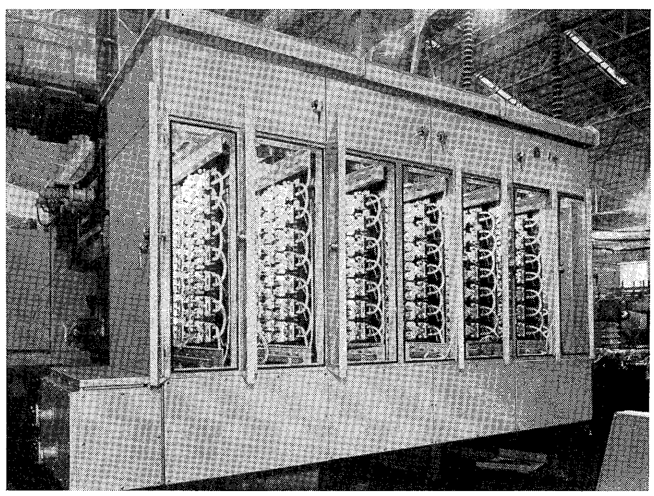


Fig. 5 110 kva 200 v dc thyristor rectifier

Table 4 **Characteristics of Power Thyristors KGP01 and GTN01**

	Item	Symbol	KGP01		GTN01		
			08	12	08	12	13
Voltage Characteristics	Max. peak reverse voltage	V_{RO}	800 v	1200 v	800 v	1200 v	1300 v
	Max. peak forward voltage	V_{FO}	800 v	1200 v	800 v	1200 v	1300 v
	Critical rate of rise of off state voltage	dv/dt	200 v/μs PFV/6		20 v/μs		
	Forward voltage drop	V_F	≦1.6 v at 1500 amp		≦1.5 v at 600 amp		
Current Characteristics	Specified average forward current (50Hz sinusoidal half wave, flow angle: 180°, with standard cooling device)	I_F	550 amp		200 amp		
	Forward/reverse leak currents (peak value at V_{FO}, V_{RO})	I_{FO}, I_{RO}	≦20 ma		≦10 ma		
	Permissible forward current rise factor (final value reached: 1500 amp)	di/dt	50 amp/μs		50 amp/μs		
	Holding current	I_H	≦400 ma		≦180 ma		
	I^2t limit value	I^2t	410,000 amp²-sec		240,000 amp²-sec		
	Permissible current during one cycle	I_S	10,000 amp		6300 amp		
Temperature Characteristics	Permissible junction temperature	Tj	−40°C∼+125°C		−40°C∼+125°C		
	Thermal resistance (between junction and base)	Rth	0.04°C/w		≦0.17°C/w		
Switching Characteristics	Turn-on time (25°C)	t_{on}	≦5 μs		≦5 μs		
Gate Characteristics	Static gate trigger current (25°C)	I_{GT}	≦300 ma		≦300 ma		
	Static gate trigger voltage	V_{GT}	Min. 0.2 v (125°C) Max. 2.0 v (25°C)		Min. 0.2 v (125°C) Max. 3.0 v (25°C)		
	Permissible average gate loss	W_{GT}	4 w		2 w		
	Permissible peak gate loss	W_{GS}	70 w (pulse width 100 μs)				
	Permissible gate reverse voltage	V_{GR}	2 v		2 v		
Mechanical Characteristics	Standard binding pressure or torque		1000 kg•m		6 kg•m		
	Element weight		240 g		55 g		
	Anti-vibration characteristics (under standard installation condition)		5 G		5 G		

Table 5 **Supply List of Thyristor Rectifier for Electrolysis Plant**

User	Equipment Ratings	Element Used	Electrolysis	Delivery Date
Tsurumi Soda Co.	100 v 12,000 amp 1200 kw	GTN01	Brine	April 1967
Nippon Light Metal Co.	370 v 15,000 amp 5550 kw	GTN01	Aluminum	Feb. 1968
Kureha Chemical Ind. Co.	200 v 330,000 amp 60,000 kw	KGP01	Brine	Feb. 1969
— Co.	400 v 12,000 amp 4800 kw	GTN01	Metals	Feb. 1969
Chiba Enso Kagaku Co.	130 v 290,000 amp 37,700 kw	KGP01	Brine	Dec. 1966

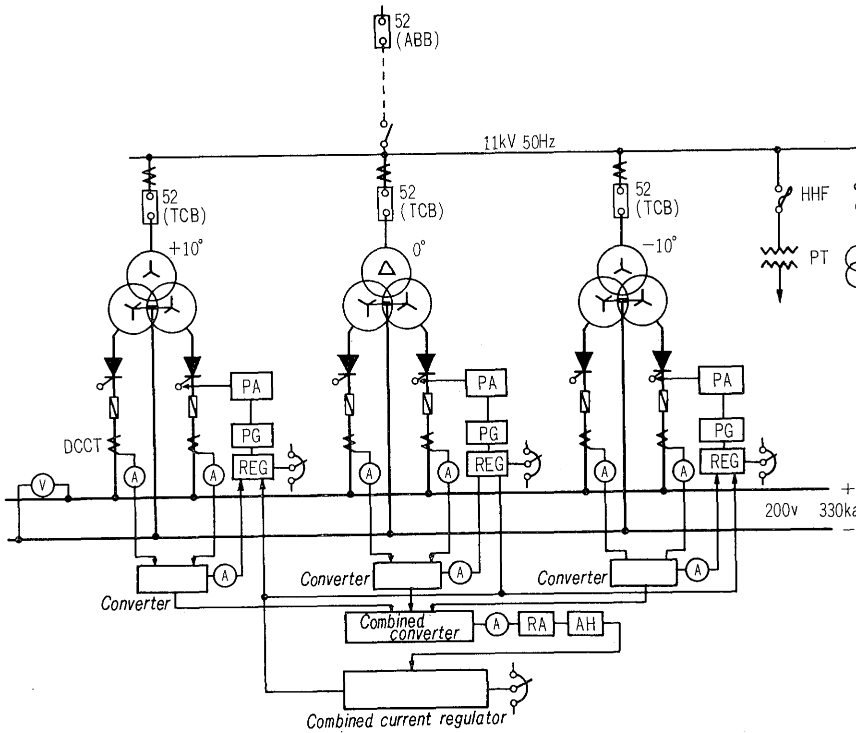
protection equipment are also included. Further details will be published in this review at a later date. At present the equipment is working satisfactorily.

VI. APPLICATION REVERSIBLE THYRISTOR CONVERTERS FOR COPPER ELECTROLYSIS

As was described previously, most general electrolysis systems are for a uni-direction constant current but recently, a system by which the current can be reversed has been developed for copper electrolysis. This system was previously invented in Bulgaria and put into practical application. Last year a similar system was discovered in Japan and has now been patented.

In this system as can be seen from *Fig. 7*, the current periodically changes between forward and reverse electrolysis. With this system, the current density is twice as high as in former systems and the productivity is much higher. Therefore, even if the price of the power source equipment increases or the power unit rates are somewhat higher, this system is much more economical in respect to cell operation and the number of persons required.

The most suitable dc power source for this type of equipment is considered to be a silicon rectifier combined with a switch for polarity conversion. However, it is impossible to provided a dc switch for continuous operation at several or quite a few Mw of power, more than several 10,000 amp of current and 500,000 or more of circuit switchings. Therefore, the use of thyristor equipment is limited in practice. In such cases, it is possible to consider silicon rectifiers and thyristor dc switches, but double



PA: Pulse amplifier
PG: Trigger phase shifter
REG: Current regulator

Fig. 6 Skeleton diagram of 200 v 330 kva thyristor rectifier installed in Kureha Chemical Industry

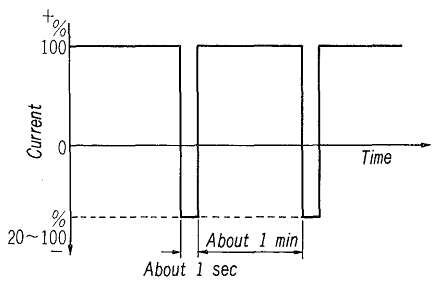


Fig. 7 Positive and negative current flow system for copper electrolysis

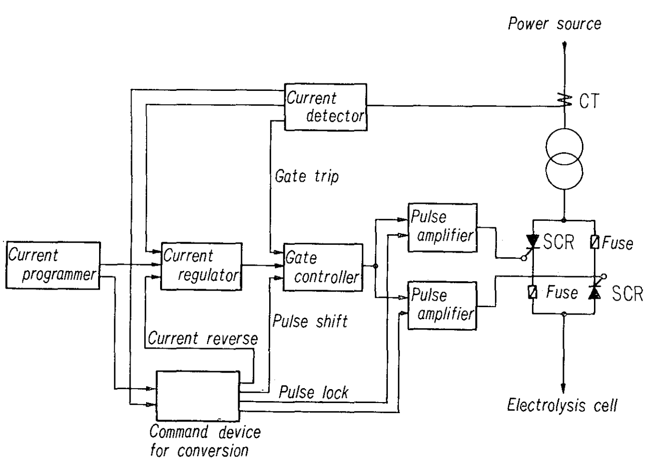


Fig. 8 Skeleton diagram of reversible thyristor converters for copper electrolysis plant

thyristor convertor with anti-parallel connections present fewer technical problems and are more economical.

Fig. 8 is a skeleton diagram of a reversible thyristor converter. As can be seen from the figure, this system has been employed in motor application equipment. The anti-parallel connection thyristor Leonard power source and control section are essentially the same but these systems contain in addition reverse thyristor elements, reverse pulse amplifiers, command mechanisms for positive conversion and a programmer for the current setting section. The rectifier transformer, positive thyristor elements and common use rectifier cooler have ratings which allow continuous passage of either electrolysis current. The reverse thyristor elements connected in parallel can be made less than the positive elements by calculating the reverse pulse current and the load time factor.

This type of reversible supply system was first delivered to Bulgaria in units of 6 Mv ±200 v ±30 ka by Siemens and since then various units have been manufactured. This type of experience will also soon be realized in Japan. Detailed examples of the type of experience gained by Siemens have already been reported in this review.(4)

It has also been possible to achieve reductions in periodic pulse conditions of forward current by means of high current density operation. If the usual thyristor converter is used in such cases, it is only necessary to add a current setting programmer. At present investigations are underway to see if the same effects can be achieved with such systems in hydrometallurgy also.

VII. DC POWER SOURCE EQUIPMENT FOR SEA WATER DESALINIZATION

In the past few year's, ion exchange membrances have been utilized for the production of salt. In this process, dc current is passed through the membrance and the sea water is desalinized. (It is also possible to make fresh water from salt water by this process). As can be seen from the supply list in *Table 6*, Fuji Electric has supplied various types of thyristor rectifier equipment as dc sources for these types of salt plants. In these plants, there are many lines and automatic fixed current operation must be performed independently for each line. At Fuji Electric, this equipment is produced economically by employing the systems described below.

One rectifier transformer is provided for an appropriate number of electrolysis lines and it is connected in parallel with a corresponding number of rectifiers. Since simultaneously changing the voltage of all the times together is unsuitable for voltage regulation by means of the on-load tap changer of the transformer, each rectifier is equipped with a 3-phase hybride bridge consisting of thyristors and diodes. In this way, voltage regulation between 500 and 850 v can be carried out independently on each line. Voltage regulation is also carried out by the no-load tap-changer of the transformer in respect to seasonal variations in the load characteristics.

Since the thyristors and diodes are connected directly to the molded bushing of the transformer secondary terminals (Fuji Electric calls these " thyristor bushings "), cooling is simple and the rectifier parts are connected directly to the transformer tank as bushings, the transformer-rectifier unit is very compact. When the output voltage is high, a thyristor bridge is used for the voltage regulation range and a diode bridge is used for the non-adjustable set voltage as shown in *Fig. 9*.

Table 6 **Supply List of Thysistor Converter for Brine Condensation**

User	Equipment Specifications	Delivery Date
Akaho Kaisui Kagaku Co.	Dc 850 v 365 amp ×5 lines	June 1967
Naruto Engyo Pertnership	Dc 850 v 365 amp ×2 lines	July 1967
Akaho Kaisui Kagaku Co.	Dc 850 v 365 amp ×3 lines	Feb. 1969
Naruto Engyo Pertnership	Dc 850 v 365 amp ×4 lines	Dec. 1969

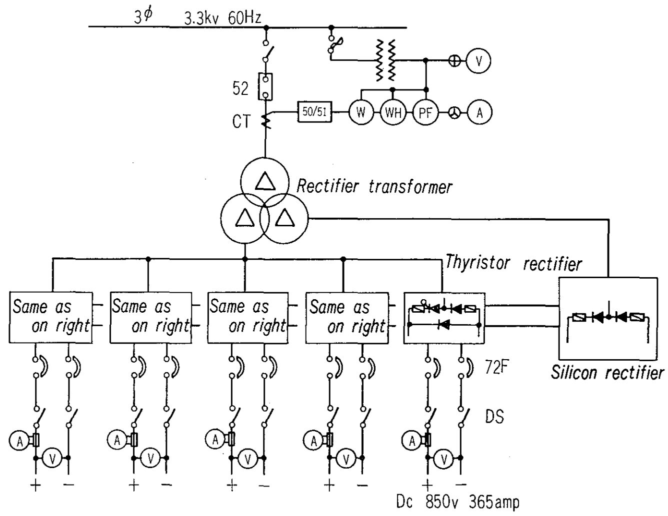


Fig. 9 **Skeleton diagram of dc power supply**

Fig. 9 shows a skeleton diagram of this type of power source equipment. The thyristors employed are Fuji Electric's standard stud type GTN01 thyristors, while the diodes are of the Si250.3 and Si250.3R types (reverse polarity construction). The control equipment is the same as that used for ordinary electrolysis processes, but it is more compact.

VIII. CONCLUSION

This article has given an outline of the application of thyristors in rectifiers for electrolysis plants. In order to make thyristor rectifiers suitable for thyristor plants, they must be at least the same or superior to diode systems in respect to economy and capacity. The use of the reversible thyristor rectifier described in section VI for copper electrolysis also looks promising for other systems. Even if such applications are completed, there will still be some problems. It is necessary to lower the costs of mass-producing thyristors, and make them more widely applicable in various electrolysis processes.

References

(1) Mizushima: Fuji Electric Journal, Special Issue on Silicon Rectifiers for Electrolysis (1960)
(2) Annual report of J.I.E.E (1968)
(3) Mizushima, Shimizu et. al., Fuji Electric Journal **39**, No. 9
(4) Fuji Electric Journal **40**, No. 11