UDC 621. 314. 63

DC 200V 330,000A THYRISTOR RECTIFIER EQUIPMENT FOR BRINE ELECTROLYSIS

Tatsuo Shimizu

Shoji Watanabe

Industrial Application Dept.

Akira Takai

Matsumoto Factory

I. INTRODUCTION

The electro-chemical industry requires low voltage and large currents, as well as a big DC power supply. In recent years, power supply equipment of several hundred thousand amperes DC has been used in brine electrolysis plants and equipment of around 200,000 kW has been employed in aluminum reduction plants.

AC power as a source of DC power formerly depended mainly on commercial power but because of the great increases in power demands, many companies have also been using private thermal power plants recently. These private power plants are not only intended for supplying power ; but they are also often used to supply the steam required in the production process of the chemical plant. Therefore, interruptions of these private power supplies must be avoided at all costs. In comparison with former cases where power was supplied only from commercial networks, the rectifier equipment which makes up the majority of the load requires an exceptionally good control system as well as high reliability.

In large capacity brine electrolysis plants, the voltage control of the DC power supply equipment must agree with the general electrolysis equipment and the the following requirements must also be met.

(1) There must be fast automatic control of the load in respect to rapid change in the supply conditions of either the commercial or private supply systems when both are operating simultaneously.

(2) There must be rapid control of the electrolysis current in accordance chlorine requirements. It must be possible to introduce computer control.

(3) Since the electrolysis equipment is very large and requires a vast amount of equipment investment, construction costs must be economical.

(4) The area required by the equipment must be a minimum and it must also be possible to use it outdoors.

(5) Since the plant has been designed so that only a few electrolysis cells were initially provided and the numbers are to increase as time goes on, there must be a high power factor and high efficiency even when only a small number of cells are operating.

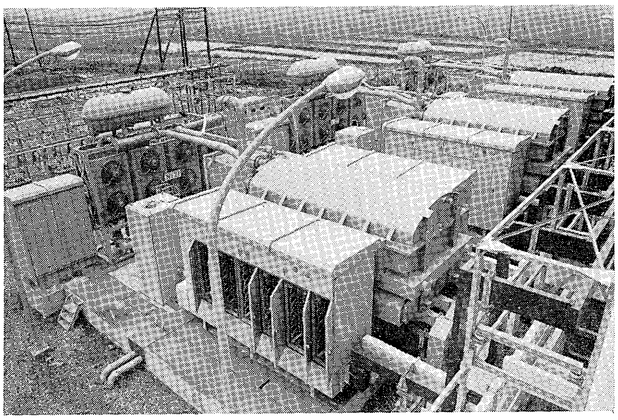

Fig. 1 Outer view of rectifier equipment

The results of investigations into the various problems concerned with DC power supply equipment for brine electrolysis have shown that the thyristor is ideal in such applications as was reported previously.[1]

This report mentioned the DC 200 V 330 kA 60 MW thyristor rectifier equipment for the Nishiki brine electrolysis plant of the Kureha Chemical Industry Co., Ltd.

This equipment has been operating successfully since March, 1969, and this article will give a general outline of the equipment. *Fig. 1* is an outer view of th erectifier equipment.

II. OUTLINE OF RECTIFIER EQUIPMENT

1. Planning

The AC power station of the Nishiki plant is to have three private generators and also use commercial power. During the initial stage of the project 40 MW are to be supplied from the private generators and it is planned to construct the private generator units for this rectifier equipment in 1970. The electrolysis cells are also to be increased in three stages with 75 V 330 kA for the first stage, 137 V 330 kA for the second and 200 V 330 kA for the third. The plant also has the following requirements:

(1) There must be load control suitable for controlling the chlorine and steam used in the plant.

(2) The DC voltage must be boosted up for short periods.

(3) The efficiciency and power factor must be high during all three of the planned stages.

As a result of exhaustive investigations into these various requirements, Fuji Electric recommended the use of thyristor S-formers with a series/parallel connection change over system for the DC winding connections.

2. Basic Electrical Specifications

AC power supply

First stage: 40 MW thermal power generating plant

Second stage: 60 MW thermal power and 15 MVA from system power supply (Power company)

Supply voltage: 3-phase 11,000 V 50 Hz

Rectifier equipment

Ratings: DC 200 V 330 kA 66 MW

No. of units: 3

Ratings of each unit: DC 200 V 110 kA 22 MW

No. of rectification phases: 18

Control system

Automatic constant current control system

No-manned remote control

Location

Main equipment: outdoors

Automatic regulator cubicle: outdoors

Auxiliary control cubicle: outdoors

Control switchboard: indoors (Central control room)

3. Main Circuits and Equipment Layout

Fig. 2 is a one line diagram showing the main power circuits of this rectifier equipment. The equipment consists of three units arranged side by side, all of which can be remote controlled arbitrarily either by individual auto-control or master auto-control. *Fig. 3* shows the layout of the rectifier equipment. The 11,000 V is received in the outdoor type steel structure and a lightning arrester, measuring potential transformer and auxiliary power transformers are arranged nearby. The cable connects this steel structure with the rectifier equipment and there is also a 7.5 meter passage way for bringing in materials between the steel structure and the rectifier equipment. The unit circuit breaker on the thyristor transformer-rectifier unit is the popular Fuji Electric minimum oil circuit breaker (T–CB) with ratings of 12 kV 2,000 A 500 MVA. It is mounted on the unit as shown in the figure. Although it can not be

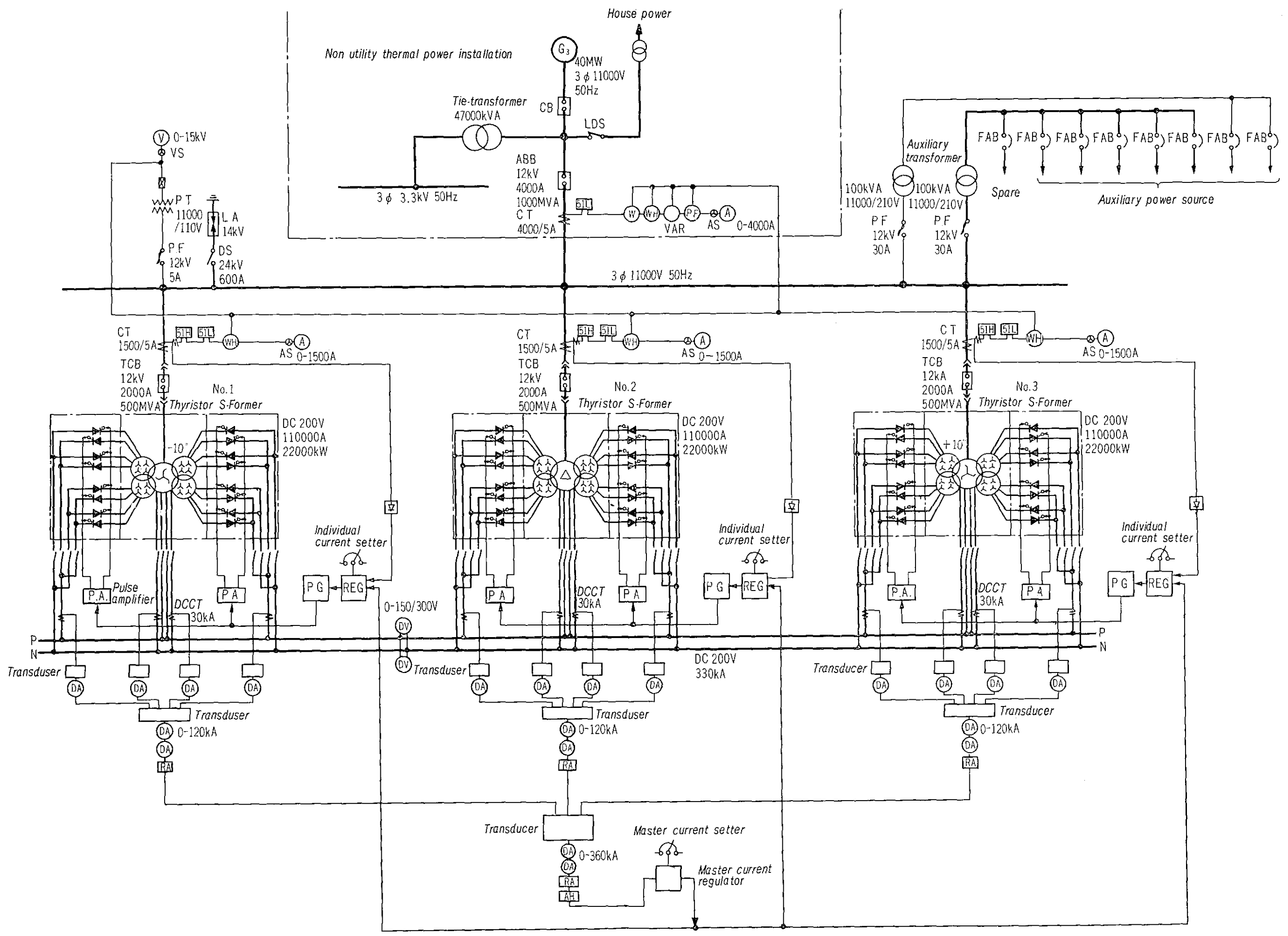

Fig. 2 Outline diagram of 200 V 330,000 A thyristor rectifier equipment

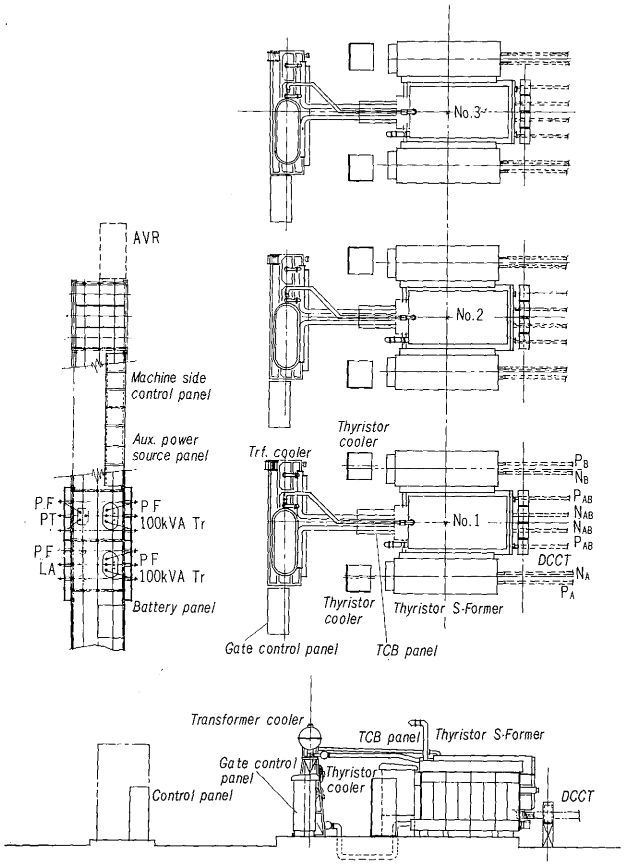

Fig. 3 Layout of rectifier equipment

shown in the figure, the incoming power breaker is a 12 kV 4,000 A 1,000 MVA air blast circuit breaker encased in an outdoor type cubicle arranged on the power station output side.

Even though the three thyristor S-former units have total ratings of DC 200 V 330 kA, they are very compact and can be accommodated in an area 27 m wide and 24.4 m deep which includes the electrolysis cell bus lines.

Between the DC bus lines and DC output terminals, there are DC current transformers. The rectifier connections are single way connections with interphase transformers, but since the in-phase contrapolarity connection system which was described previously in this Review is applied, the inter-phase transformer is incorporated inside the transformer tank.

III. THYRISTOR S-FORMER SPECIFICATIONS

1. Capacities of Individual Units

The ratings and capacities of the individual units of the thyristor S-former are as follows.

AC side: 26,900 kVA 11,000 V 50 Hz
DC side: 22,000 kW 200 V 110,000 A
Rectifier transformer: outdoor, forced oil forced air cooling
Thyristor rectifier: outdoor, circulating water cooling system with water to water heat exchanger
Voltage regulation range: 0~200 V, 100% adjustable
Standards: JEC-168, JEM-56
External dimensions: width (X): 6,470 mm
depth (Y): 5,830 mm
height (Z): 5,390 mm
Overall weight: 88,700 kg
Total oil volume: 26,700 *l*

Fig. 4 shows the external dimensions of the thyristor S-former.

2. Specifications and Ratings of the Transformers and Rectifiers

1) Specifications of rectifier transformers
Connections: AC side wye or delta
Phase shifting 1 unit: delta 0°
1 unit: wye + 10°
1 unit: wye − 10°
DC side single way with interphase transformer
Rated capacity
AC side 26,900 kVA
DC side 8 × 2 × 2,380 kVA
Rated voltage
AC side 11,000 V
DC side (phase voltage) 200/100 V
Number of phases
AC side three phases 1,412 A
DC side 2 × three phases 8 × 2 × 3,970 A
Frequency 50 Hz

2) Specifications of rectifier
Rated DC voltage DC 200 V
Rated DC current 110,000 A
Rated output 22,000 kW Rating Ao (JEM)
Connections (6-phase double-wye) single way
Thyristor rectifier cells Model KGP01
Composition
No. of series cells 1
No. of parallel cells 56
No. of arms 6
Total no. of cells 336

IV. FEATURES

This thyristor S-former incorporates several new features based on Fuji Electric's rich experience and achievements in the fields of high current electric furnaces transformers, rectifier transformers and water cooled rectifiers. These features can be listed as follows:

(1) It employs systems which are designed for use in connection with thermal power plant equipment.
(2) It is the world's biggest thyristor rectifier equipment.
(3) It has a series/parallel connection changing system for the DC windings (secondary) of the transformer which insures high efficiency and power factors even when the DC voltage is low.
(4) Special flat-packaged type thyristor cells developed for the low voltage and large currents required for electrolysis are used.
(5) The rectifier assembly is very compact in spite of its large capacity.

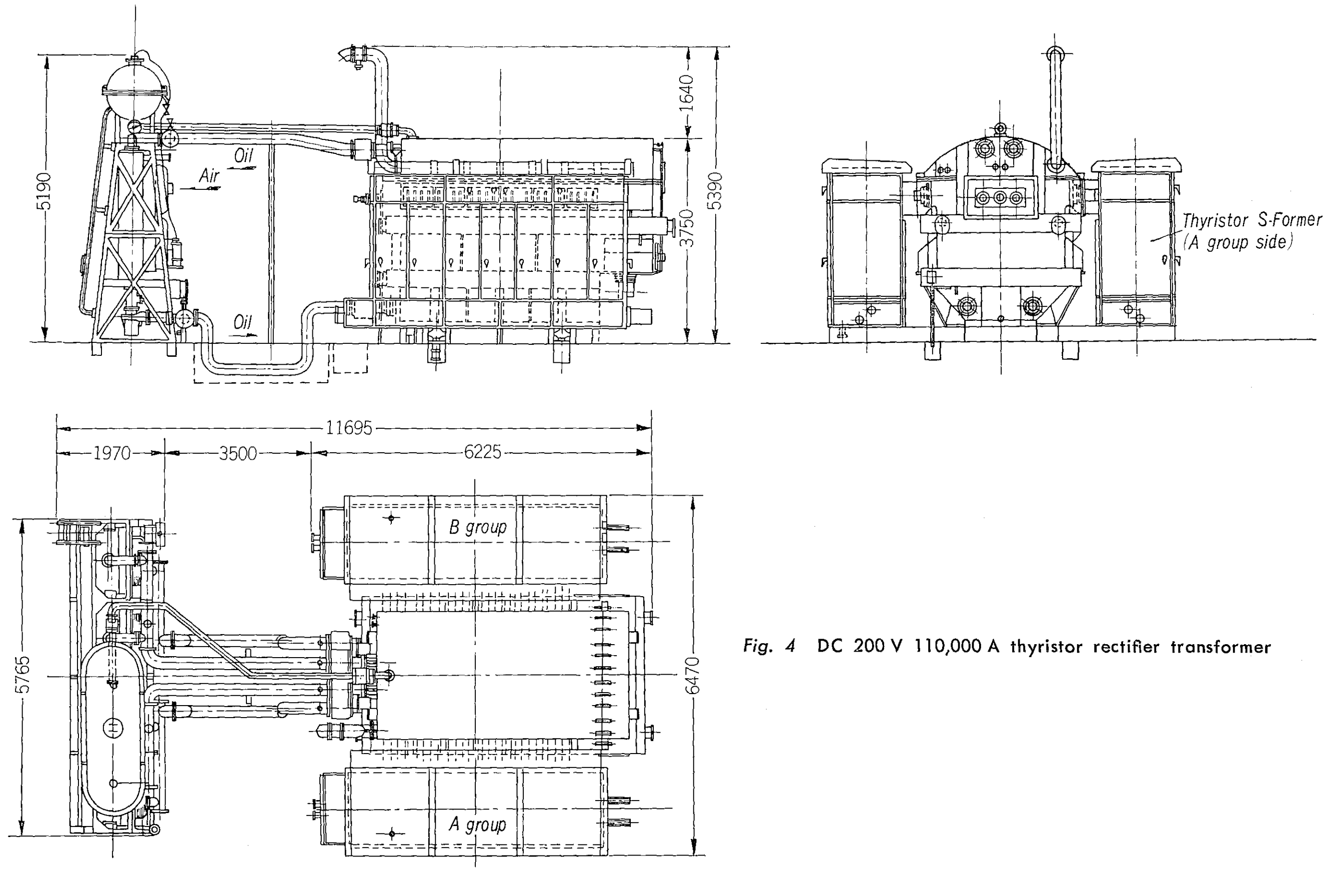

Fig. 4 DC 200 V 110,000 A thyristor rectifier transformer

V. CONTROL OF POWER REQUIREMENTS BETWEEN THERMAL POWER PLANT AND THYRISTOR S-FORMER

In the first stage, 40 MW (pf: 0.8) generator supplies electric power to the thyristor S-former. This private generator is connected to the existing 3.3 kV system lines through a 47 MVA 11/3 kV power transformer.

Therefore, the power distribution in both the generator and the system lines was a problem, but this was solved by careful selecting the taps of the 47 MVA transformer.

Since the private generator is connected in parallel with the system power network via 10 and 20 MVA 66/3.3 kV power transformers, the private generator momentarily becomes overloaded when a system power supply is interrupted. To prevent such a problem when interrupted and power interruption signal is received, the load is limited by the shifting trigger gate angle α of the thyristor S-former and therefore the private generator is not overloaded. As was mentioned previously, the output voltage for the first stage is DC 75 V and when α is controlled from 200 V down to 75 V the power factor becomes so low that it can not be used in practice. Therefore, the generator output voltage becomes 10,500 V and series/parallel connection changing of the DC windings of the rectifier transformer which will be described later is applied. This results an improvement of the rectifier power factor. Therefore, it is not necessary to install a new capacitor to improve the power factor and the existing capacitor on the 3.3 kV side is sufficient. After the second stage, it is planned to construct a 60 MW private generator employing a thyristor S-former. Plans for this thyristor S-former are now that 80% of the generator output voltage will be adjustable as a result capacitor follow up is also not required at such times. High harmonic current have also been investigated and 18 phase rectification with three units is adopted.

VI. SERIES/PARALLEL CHANGING SYSTEM OF TRANSFORMER DC WINDING IN RELATION TO POWER FACTOR AND EFFICIENCY

1. Boosting System for Rectifier Equipment

In ordinary rectifier equipment the wide voltage boost required is accomplished in the following ways:

(1) Single way to double way connection change

When the single way system is switched to a double way bridge connection, the later output voltage is about twice that of former but the output current becomes about half.

(2) Y–△ connection change in the transformer AC windings

When the AC winding connections are changed from Y to △, 1.55 to 1.6 times the output voltage can be achieved. However, when the unit is combined with parallel and the components have a large number of rectification phases, care must be taken since there are many cases when this connection change is not possible.

(3) Series to parallel connection change in transformer AC windings (primary side)

When the AC windings of the transformer are changed from series to parallel connections, about twice the output voltage can be obtained.

(4) Connection of a booster transformer

With this method, the DC winding of a rectifier booster transformer is connected in series with the DC windings of the S-former. The voltage can be boosted right up to the permissible voltage limit of the rectifier cells.

(5) Booster rectifier

The existing rectifier is left as it is and a new rectifier is connected in series to one end of the DC bus line. The amount the voltage is boosted is arbitrary with this method.

However, if the DC output current is constant, the total loss is almost constant in spite of the variations of the output voltage in all these methods except (4) and (5). At the time of the low voltage before the voltage boost, there is an unavoidable drop in efficiency and power factor.

2. Development of the Series/Parallel Connection Changing Method for the Transformer DC Windings and the Efficiency

One of the prerequisites of this project was that the efficiency and power factor be excellent during the first and second stages. With methods (1) to (3) described above, it is difficult to achieve this goal and therefore methods (4) and (5) were investigated. Although method (4), the use of a booster transformer, is highly effective, Fuji Electric decided not to use it mainly because of the increase in space occupied and for economy reasons. This method has been used often but in every case, there were no space problems and it was considered effective only if the operating time of the first stage was sufficiently extended.

If this system were applied for this project, 2 booster transformers were arranged on either side of the S-formers. In such a cases, the width of the space occupied would be increased more about 20 m. Considering the economic use of the factory land it is difficult to recommend such a method. The same can also be said for method (5). When the operating time of the first stage were short, the addition of booster transformers increases the costs. In order to solve these problems, the following plan was developed.

Investigations into the rectifier equipment loss showed that most of the loss was concentrated in the DC winding of the S-former.

Since there is a large current in the DC winding, chang-over the connections from series to parallel has always been considered impossible but investigations into the details of such a method showed that it could be accomplished both economically and easily. It was therefore decided to apply this method.

The efficiency when this method is used are as shown in *Fig. 5*. As a result the load loss of the transformer during the initial stage when the connections are parallel is reduced to about 1/4 of that when the connections are in series and the efficiency is improved remarkably. This figure also shows a broken line efficiency curve when the series/parallel chang-over is not carried out. As shown in this figure, at DC 75 V, 2.4% improvement in the efficiency is achieved. The loss difference between the two cases is 5,000 MWh per year and it can be said to be very economical considering the equipment as a whole. This chang-over is possible by making a simple change from the top of the transformer and there is no increase in the space occupied like in the case when a booster transformer is used. The connection change is carried out for a short period.

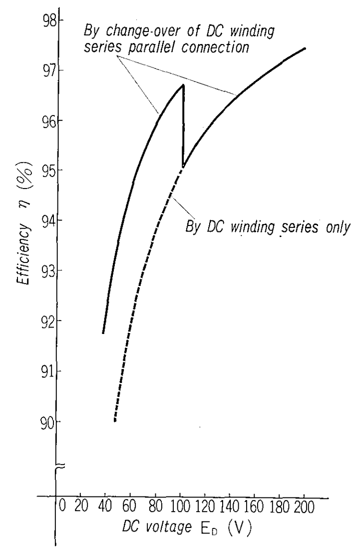

Fig. 5 Efficiency curve of DC 200 V 330 kA thyristor transformer

3. Power Factor

In the thyristor S-former, a wide range of voltage regulation is possible by controlling the thyristor gate but when the control angle α is large, the output voltage as well as the power factor drop considerably. When constant current control system is used, however, the apparent input does not change and a problem is created by the increase in reactive power which results. This is not such a problem in a small capacity thyristor rectifier equipment but in a big capacity equipment, for instant 50 or 60 MW, the power factor must always be high and it is necessary to include a capacitor to improve the power factor. The power factor in the diode type rectifier equipment is 90 to 95% and the magnitude of the capacitor would be required small capacitance.

However in the thyristor equipment, the kVA of the capacitor must be 60 to 70% of the capacity of the S-former and therefore it is essential to

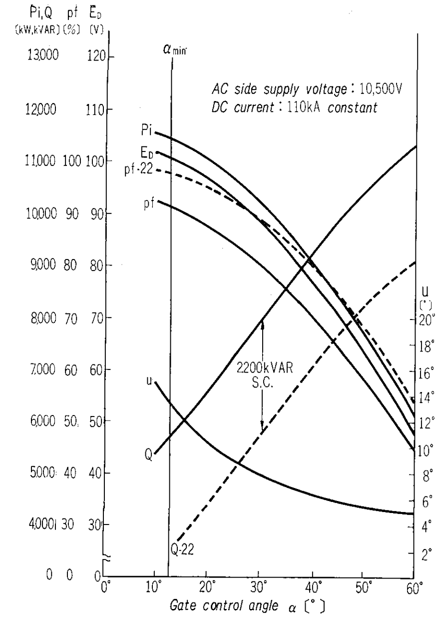

Fig. 6 The 1st stage characteristic curves of DC 200 V 110,000 A thyristor rectifier transformer

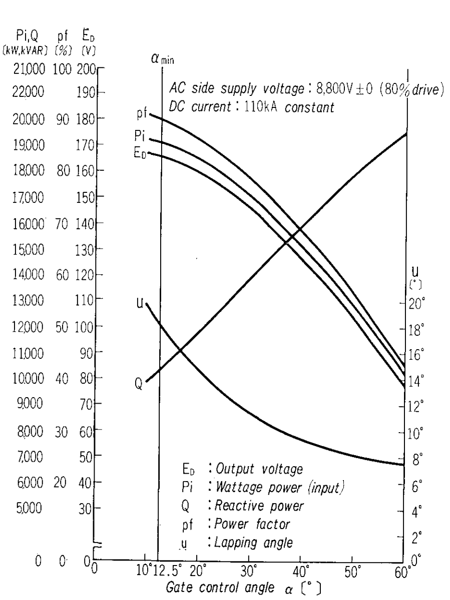

Fig. 7 The 2nd stage characteristic curves of DC 200 V 110,000 A thyristor rectifier transformer

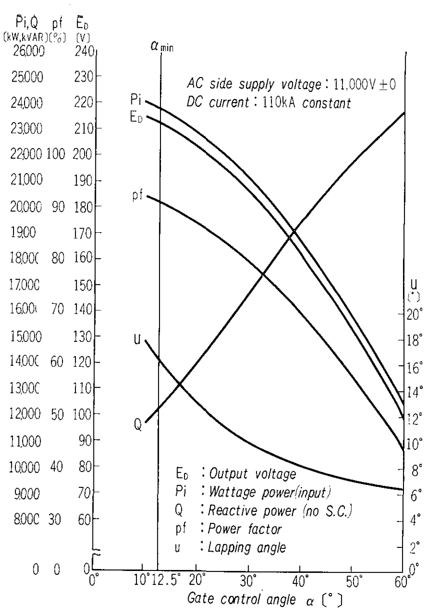

Fig. 8 The 3rd stage characteristic curves of DC 200 V 110,000 A thyristor rectifier transformer

minimize this capacitor equipment by some other means.

The power factor of a semiconductor rectifier is approximately:

$$\frac{E_D+e_r}{E_{DO}}\times 100(\%)$$

where E_D: DC output voltage
E_{DO}: DC no-load voltage
e_r: Ohmic drop in the rectifier equipment

The only means of improving the power factor is to make this E_{DO} small

The voltage boost methods (2) to (5) as listed in section 1. As well as series/parallel chang-over of the DC winding of the transformer, all play a major role in improving the low power factor during low voltages but even if these methods are used, a low power factor at the second stage voltage of DC 137 V can not be avoided since input kVA in the stage is equal to that one in third stage of DC 200 V, and the magnitude of the capacity will have to be very large. The power factor curves for the first stage are shown in *Fig. 6*. In this case, the power factor at DC 75 V was only 68%. Existing capacitor equipment of 6,600 kVA was connected on the 3.3 kV side and the power factor became 78%.

Fig. 7 shows the power factor curves for the second stage of the project. At a voltage of 11,000 V on the AC side, the power factor is reduced to about 60% in order to obtain the second stage output voltage. Since the power factor improvement capacitor must become very large in this case, it is necessary to consider where it will be installed. As a countermeasure for this, the thyristor rectifier equipment will be the main load in the future private generators and if the generator output voltage is controlled up to 80%, the power factor at the second stage will be about 75% at 137 V and capacitor equipment can be left almost as it is.

The curves shown in *Fig. 7* are for an AC side voltage of 8,800 V (80% operation). As can be seen from *Fig. 8*, the power factor will be raised to over 80% in the third stage when the output voltage is over 160 V, and a new power factor improvement capacitor is not needed by the above measures.

Therefore the power factor improvement capacitor equipment need not be considered for all the three stages of the project.

VII. DEVELOPMENT OF THE LARGE CAPACITY FLAT-PACKAGED KGP01 RECTIFIER CELL

When deciding selecting the unit capacity, it is necessary to consider the area occupied by the rectifier equipment, high harmonics and the cost of the equipment. However, among these factors, the selection of the thyristor rectifier cells which determines the construction of the rectifier which is in turn related to the cost and unit capacity is the most important. With the previously used stud-type GTN01 and high-voltage flat-packaged KGP02, a large number of cells were necessary for assembling and this can not be said to be the best from the viewpoint of technique and cost. Therefore a new cell was developed especially for electrolysis. This element is a highly efficient high-current water-cooled 550 A flat-packaged type with the model designation KGP01. With this new cell, it was possible to construct the world's largest thyristor rectifier equipment economically with ratings of 200 V 330 kA or 110 kA for each of three units and satisfy

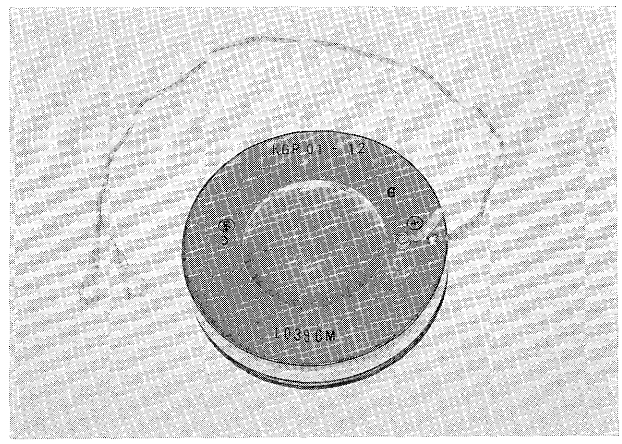

Fig. 9 Flat-package type power thyristor KGP01

customer requirements. *Fig. 9* shows an external view.

VIII. THYRISTOR RECTIFIER

1. Thyristor Rectifier Cell and Its Cooling System

This high current thyristor S-former is not only compact but it is also advisable to limit the number of cells used in order to make the control equipment as simple as possible. The above mentioned KGP01 cell has the both-side cooling system and this insures that the rated current is large.

These KGP01 cells are so arranged that even if one cell in each group fails, operation can continue at rating current.

There are 1 series and 56 parallel cells in 6 arms with an overall total of 336 cells.

The elements feature the both-side cooling method and deionized water is used as the cooling medium which increases the cooling effect due to the excellent cooling properties of water.

2. Rectifier Construction

The rectifier part of this 200 V 110 kA thyristor S-former is mounted directly on both of the long sides of the transformer and consists of 2 cubicles of 55 kA each. *Fig. 10* shows an external view of this rectifier equipment. The rectifier cubicle is of completely enclosed outdoor-type construction. The main components inside the cubicles are the thyristor cells which make up the main cirucuits and cell protection fuses as well as the pulse amplifier and protective circuits which make up the control circuits.

The cooling equipment consists of one unit for each rectifier cubicle. Each cublicle also contains a heat exchanger, water pump and ion exchanger. The rectifier cells are divided into 8 groups of single way connections in accordance with the groups of DC windings of the S-former. Since each group consists of 1 series cell, 7 parallel cells and 6 arms, each cubicle contains 168 cells and their protective fuses.

As a result of dividing the DC windings, the transient duty of the di/dt, dv/dt etc. which is applied to each cell is reduced and unbalance of the current between the parallel cells can be reduced. It is not necessary to use additional current balancing equipment such as anode reactors.

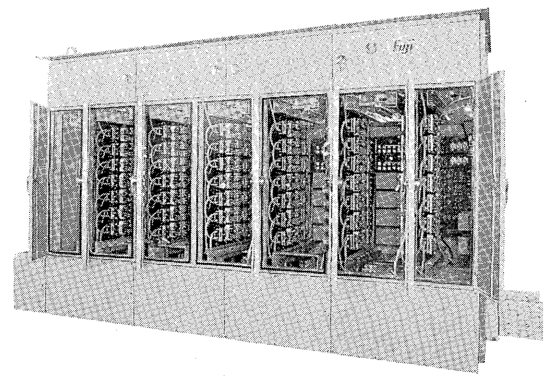

Fig. 10 DC 200 V 110,000 A thyristor rectifier

In the actural construction, the so-called in-phase contrapolarity connection system in which a current with a phase difference of 180° flows in two groups of cells arranged back to back is used. Therefore, in spite of the large current capacity per unit of 110 kA, problems of current unbalance and local heat in the cubicle caused by the magnetic field have been solved and inductive influence in respect to the pulse control circuit which is even more of a danger in thyristor rectifier equipment can be eliminated.

Fig. 11 shows the water-cooled type rectifier using a flat-packaged type thyristor cell. A DC side water-cooled conductor is connected directly to one surface of each cell, and cooling is effected by water which flows in two water ducts within the conductor. The other side of the cell is cooled by a heat sink which is independent both structurally and electrically.

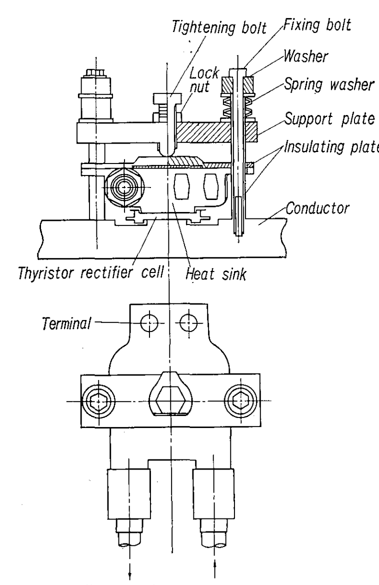

Fig. 11 Water cooled type rectifier using flat-packaged thyristor rectifier cell

The cell is sandwitched between this conductor and heat sink and pressure connected. A suitable pressure is applied via a vell-bill washer in such a way that the electrical and thermal resistance of the parts in contact remain stable. As a result, heat losses which arise in the cells are removed to the conductor and heat sink and dispersed in the circulating cooling water. The cells can be easily replaced simply by removing the tightening bolts.

The protective fuses are two Fuji super rapid SRF–3–500 fuses connected in parallel. There is a water cooled, conductor which serves as an AC side conductor attached to the fuses and the fuses which are also connected to the heat sink as described above are therefore cooled on both sides so that there is absolutely no heat transfer to the air inside the cubicle.

Water cooled conductors are also used in the bus lines. These assure greater compactness, limit heat transfer to the air inside the cubicle and prevent any increase in the air temperature rise inside the cubicle. Therefore it is not necessary to provide a cooler to cool the air inside the cubicle.

With all of the above improvements, this equipment is not only able to have large capacities but also able to be completely enclosed so that it is ideal for the atmosphere in electrolysis plants.

IX. CONTROL SYSTEM AND PULSE AMPLIFIER

All operations of this equipment are performed from a centralized control room and only periodic checks are necessary at the actual equipment. Therefore, there must be no interruptions of the control equipment and special attention must be paid to the system and its components.

1. Control System

There are two types of control system used: individual auto-control and master auto-control. Both of these are in the form of constant DC current control. *Fig. 12* is a skeleton diagram of the control system. This automatic control equipment employs Fuji's well-known TRANSIDYN system and has been simplified as much as possible. An inner view of the control cabinet is shown is *Fig. 13*.

2. Individual Auto-control

For DC current setting, a setting signal is applied to the current regulator by an oil immersed motor driven resistor. In order to prevent any time lag in current detection, rectifier transformer AC side current is converted into an equivalent DC current.

The output of the DC current detector passes through a gate pulse shifter and is then converted into a gate pulse and amplified by the pulse amplifier. Then it is applied to the gate of the each cell as an input signal. The various explanations concerned with the details of this operation mode will not be given here.

3. Master Auto-control

As in individual auto-control, a setting signal is given to the master current regulator by the oil-immersed motor-driven resistor and the output of a Hall generator type DC current transformer is used for detection. The output of the master current regulator which is operated by this deviation is applied as input to the aforementioned individual current regulator so that there is an absolutely uniform current burden in each part.

There can be arbitrary switching from master to individual control during the former and no matter

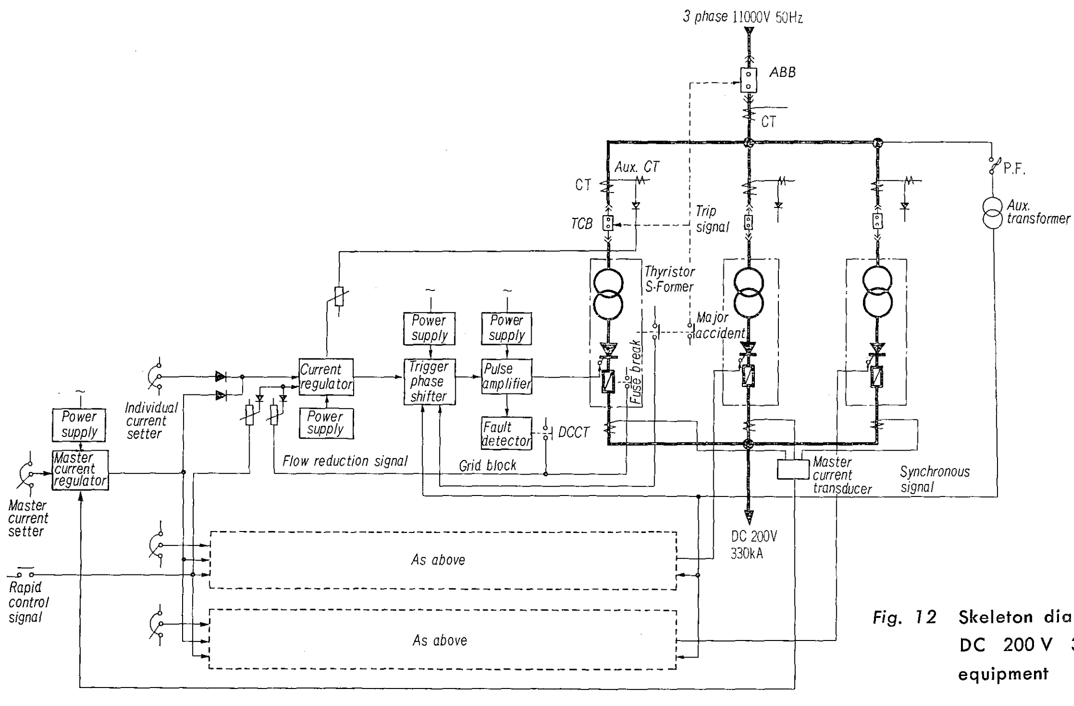

Fig. 12 Skeleton diagram of control system for DC 200 V 330,000 A thyristor rectifier equipment

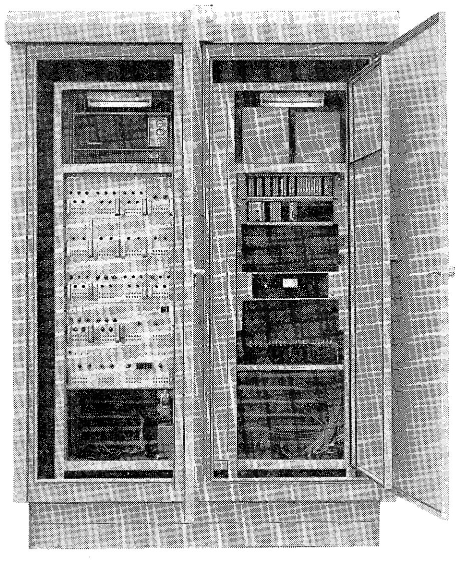

Fig. 13 Grid control cabinet

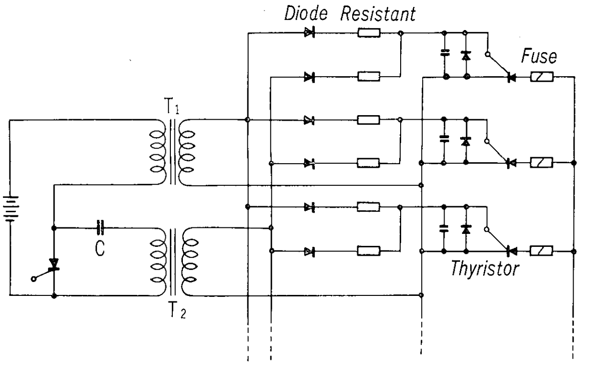

Fig. 14 Principle of pulse amplifier

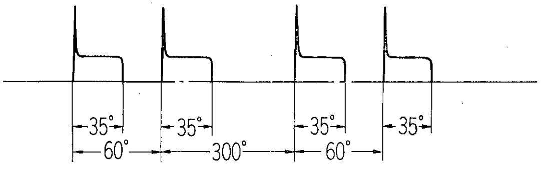

Fig. 15 Pulse wave shape of pulse amplifier

what the current value of the individual controller, master control operation can continue.

4. Pulse Generator

There is one pulse generator for each thyristor S-former. Since the output is insufficient, a pulse amplifier which will be described next is also used. The generator is also able to control current unbalances in both commutating groups because current deviation among the commutating groups (u.v.w.) and (x.y.z.) in each thyristor S-former cubicle can be measured directly by the DC current transformers.

There are no measures for inproving unbalance in the cells themselves and the planned value can be obtained within about ±5% by carefully adjusting each gate angle of the pulse generator.

5. Pulse Amplifier

The pulse amplifier receives a very small signal from the pulse generator and amplifier it into a gate pulse with sufficient energy to fire the thyristor elements. In this rectifier equipment 7 cells are connected in parallel. Each cell is connected to an RC snubber circuit to suppress surge voltages at commutating caused by the carrier accumalation effect. However when there are irregularities in the firing of the elements, a rush current from the capacitor of the seven cell group is concentrated in a specific cell and this cell fails. In order to prevent such irregularities in firing, it is necessary to supply a firing pulse with a sufficiently large rise and peak value to each cell.

Fig. 14 shows the principle of the pulse amplifier. The DC current is switched by the thyristor chopper and a 35° wide pulse arises via pulse transformer T_1. Another rapid rise peak pulse arises when capacitor C discharges via pulse transformer T_2. These two pulses are combined on the secondary side via the diode. In this way a gate pulse in the form of a large current with a wide width is rapidly applied to all cells and stable firing is possible.

When there are many parallel cells, there must usually be a large number of pulse transformers as well as a large number of feeders to connect these transformers to the pulse amplifier.

It then becomes necessary to place the pulse amplifier in a separate unit from the rectifer and this leads to large losses both in economy and characteristics due to the use of large, long cables. In this equipment, however, the pulse amplifier is arranged within the rectifier equipment close to the cells and because of the advantages of the flat-packaged type cells, they can be assembled in one arm and only one transformer is needed.

Therefore, the lines between the pulse amplifier and the cells are very short and there are few cables required to connect the rectifier and grid control cabinet. This system insures a rapid firing pulse with sufficient energy at all times.

Since the capacity of each unit in this equipment is 110 kA, it was necessary to take precautions against erroneous operation of the pulse amplifier by the high energy of the magnetic field in the cubicle. Such operation has been completely eliminated by the use of the afore-mentioned in-phase contra-polarity connections and also by providing a large noise margin. In the event that pulse amplifier chopper operation due to misfiring or faults caused by erroneous operation is detected, it is skillfully applied to the time lag of the phase sequence and a current reduction command and alarm occur. This alarm equipment uses Fuji Electric's digital circuit F-MATIC-N system and the principle is as shown in *Fig. 16*.

When u-phase is taken as an example to explain the circuitry, the u-phase flip flop FD31 is operated by a u-phase signal and is reversed by a v-phase signal. The flip-flop output signal and x-phase signal are

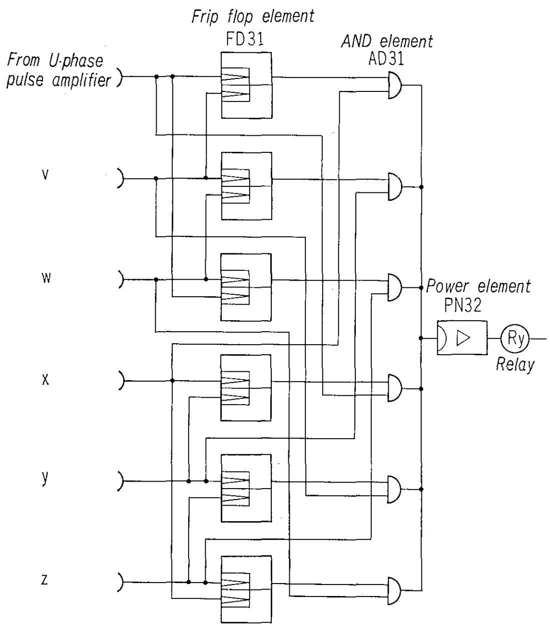

Fig. 16 **Principle of pulse fault detector**

combined in the subsequent "and" gate AD31. When FD31 is reversed, AD31 gives out a "O" signal to indicate that things are normal.

When there is a fault in the u or v-phases, FD31 continues to operate and the AD31 gives out a "1" signal. Relay "Ry" then operates, a fault indication is given on the distribution panel and a current reduction command is given to the current regulator. In case that there are faults in the v or w-phases, the operation/non-operation state of the v-phase changes in the same way, the v-phase AD31 gives out a "1" signal because of combination of y-phase signal. When this continues in succession, protection against all pulse faults is possible.

With this fault protection, sudden changes in the load current can be avoided and there is no stoppages, only a decrease in the current flow. When there is a fault in one phase, and there is only one group of double way connections, the phase before the faulty phase (like the w-phase when there is a u-phase fault) still continues the current flowing. However, when there are several groups like in this equipment, the current is shifted to an arbitrary phase U′-phase of the same phase as the fault phase by the ampere turn method. In other words, outwardly, there appears to be no change in the DC output current but the arbitrary phase current is a maximum of twice the normal rating and there is in effect a 200% overcurrent. This overcurrent phase u′ is determined by the arrangement of the transformer windings. In practice, the coupling between the phases is strong because of the in-phase contrapolarity connections and 200% is not actually achieved so that the current burden is somewhat less. In other words, the current reduction commands must be a maximum of 50%.

6. Construction of Control Device

The above has been an outline of the control system. The control device and for thyristor rectifier equipment should be arranged near the equipment and various schemes were worked out. In comparison with silicon diode rectifier equipment, there are more circuits and components in this equipment.

It was planned to place the device in units as much as possible in order to simplify maintenance. The cubicles construction of control device was formed of double cubicle and coolers were installed to avoid air temperature rise inside the cubicles and also allow for them to be completely enclosed. The oil immersed type were used for all the set resistors and electrical operations are all made by remote control.

X. TEST RESULTS

This equipment was assembled at the Chiba Factory of Fuji Electric and it went to operation after final control tests using water resistors were conducted at the site. Goods results were obtained as anticipated and thus the world's first 330 kA class thyristor rectifier equipment came into being.

XI. CONCLUSION

DC 200 V 330 kA thyristor rectifier equipment employing the latest techniques has been completed for use in the world's largest brine electrolysis plant. Problems concerning the improvements of efficiency and power factor at low voltages, reduction in construction costs and measures in respect to the supply and demand of both private and commercial power have been solved and the equipment has been operating smoothly for 3 years.

On the basis of the experience gained with this equipment, DC 130 V 290 kA rectifier equipment has been completed for the Chiba Chlorine Chemical Co. and equipment of similar capacities is now being manufactured for other companies. The use of thyristor features in this type of large current brine electrolysis plant as well as their use in rectifier equipment will probably increase in the future. Fuji Electric is offering this type of equipment with high performance, high reliability and excellent economy to satisfy all customers' wishes.

The authors would like to thank sincerely those persons at the Nishiki Factory of the Kureha Chemical Industry Co., Ltd. for their technical guidance in this project and also for permitting this equipment to be described here.

References:

(1) Fuji Electric Review Vol. 15 No. 6 pp 195~202 (1969)