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LATEST TECHNOLOGY OF RECTIFIER EQUIPMENT FOR ALUMINUM SMELTERS

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I. FORWARD

Recent trends in aluminum reduction plants is that the size of electrolysis pots becomes so large that the annual production per one potline has exceeded 100,000 tons. Therefore, the electrolysis power consumed by one potline has reached 200 MW and the total power consumed in one plant is 500 to 1000 MW.

The increased usage of equipment containing semiconductors such as thyristors and diodes has been accompained by an increase in the higher harmonics generated by those equipment and the possibility of having unfavourable effects on devices parallel connected to the power system as well as on the communication lines in the vicinity.

To cope with this situation, power companies are establishing regulations to suppress the higher harmonics generated by power users within certain limits. In most cases, the amount of voltage distortion or higher harmonic current at the point of common coupling is regulated. In other cases there may also be limitation for TIF or THFF to prevent telephone interference. *Tables 1* and *2* list the tentative regulations of some Japanese power company as an example.

To suppress the voltage distortion to a lower value, it is very important for rectifier system to be connected to a lower impedance network, as well as making the harmonic current smaller. This generally shows that receiving power from a higher voltage network is advantageous. In this sense, the rectifier equipment delivered to China through Nippon Light Metal Co., Ltd. was designed as the world's first direct step-down system from 220 kV and highly significant. This system is outlined in part II.

Another trend reflects the continuing rise of the cost of energy and is the demand for higher conversion efficiency. One means of achieving this is the practical application of the world's first thyristor rectifier equipment for high capacity aluminum smelting. This equipment is introduced in part III.

Table 1 Permitted harmonic current

Harmonic Number	5	7	11	13	17	19	23	25
Current (Amps)	10.6	5.0	2.6	2.2	1.8	1.7	1.8	1.9

NOTE) Applied to the system voltage above 66kV.

Table 2 Harmonic voltage distortion limits

System voltage	Individual harmonic	Total
above 154kV	0.5%	1.0%
below 66kV	1.0%	2.0%

II. DIRECT STEP-DOWN SYSTEM FROM 220 kV

1. Outline of the system

Operation of rectifier equipment for aluminum smelters using direct step-down from 220 kV was started in December 1981 in Guizhou, China. This equipment was delivered by Fuji Electric for an 80,000 tons/year facility constructed by Nippon Light Metal Co., Ltd. Its ratings are outlined below.

Potline rating	: DC 920 V, 160 kA, 147.2 MW
Number of rectifier units	: 4
Unit rating	: DC 920 V, 56 kA, 51.52 MW
Pulse number	: 48 pulses with four units in operation
Primary input voltage	: 220 kV, 50 Hz

Fig. 1 is a skeleton diagram of this system. *Fig. 2* shows its layout. To maintain a 95% mean power factor at the power receiving point, a 12.5 MVAR capacitor bank is connected to the tertiary winding of each rectifier transformer.

A 48 pulse system was applied to suppress the overall voltage distortion ($= \sqrt{\sum_n \Delta V_n^2}$) at the power receiving point to 1.0% or less.

The conversion efficiency at 920 V, 160 kA (4 units) operation is more than 98%.

As can be seen from the layout of *Fig. 2*, the installation space, including the substation and rectifier bay has

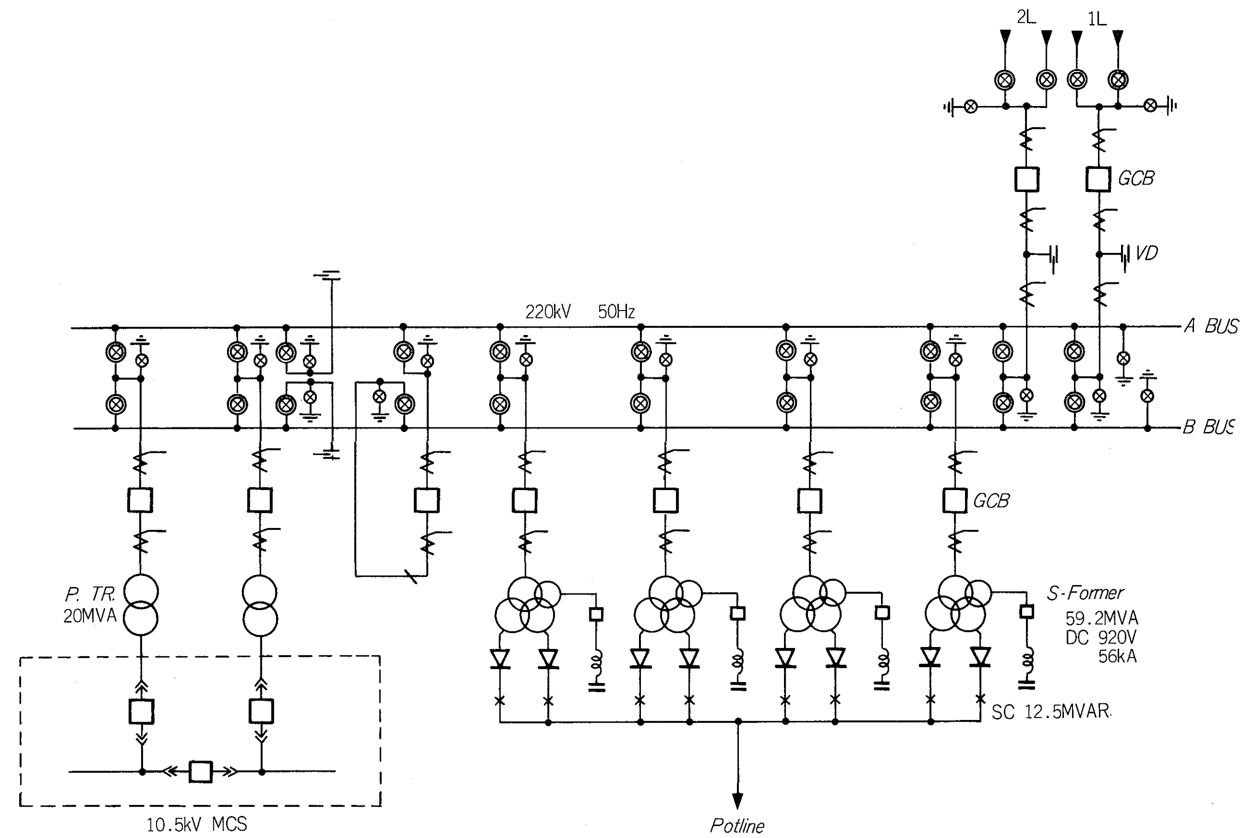

Fig. 1 Skeleton diagram

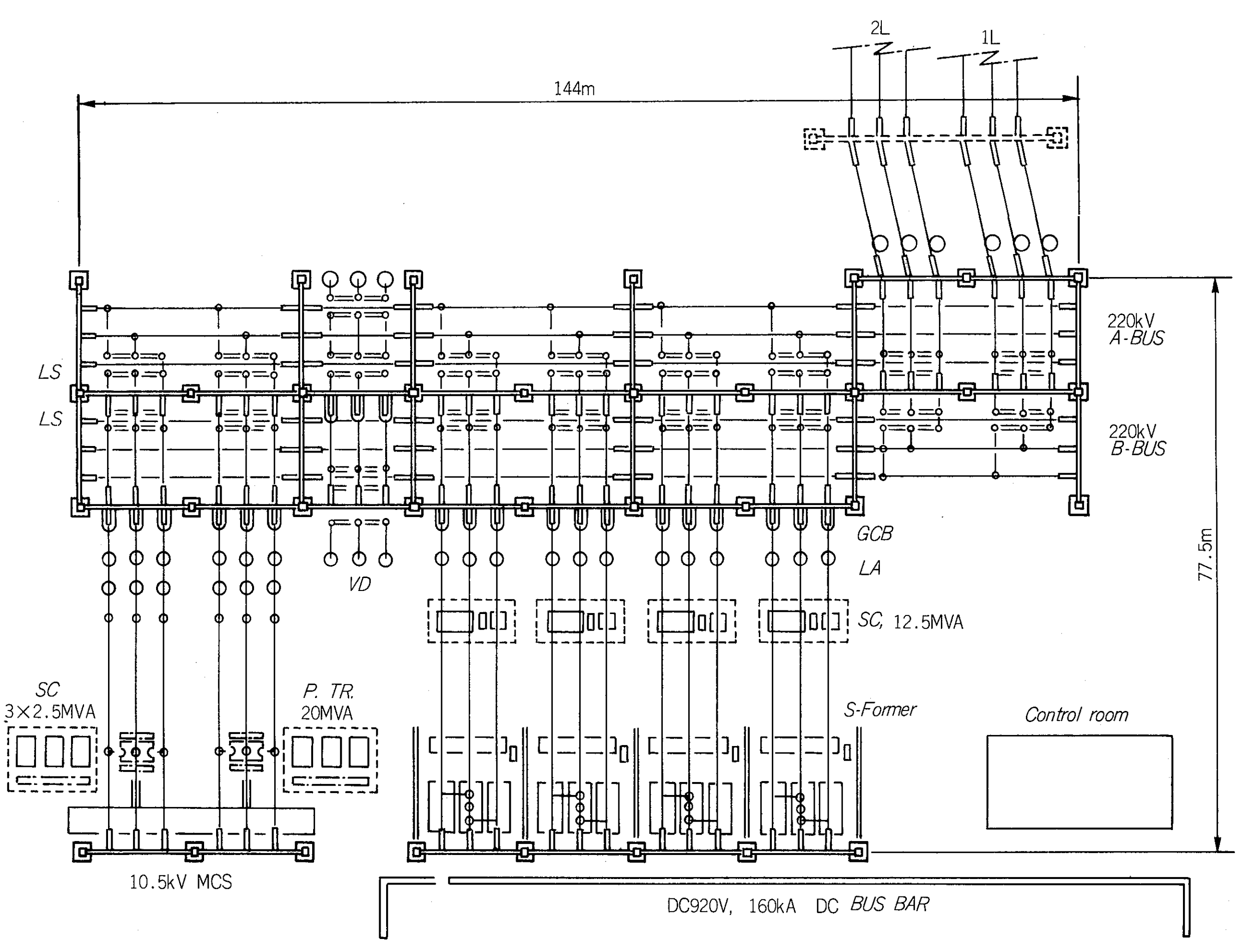

Fig. 2 S-Former and 220 kV substation layout

been reduced to about 75% of that of the conventional system with intermediate voltage.

2. Rating and features of main equipment

(1) Rectifier transformer

Rated capacity	
Primary	59,200 kVA
Secondary	4 x 15,320 kVA
Tertiary	12,500 kVA
Rated voltage	
Primary	220 kV
Secondary	F839-R774-397 V (35 taps)
	474.6 V-32.6 V (35 taps)
Tertiary	10.27 kV
Frequency	50 Hz
Voltage control range of saturable core reactor	60 V DC
Connections	
Primary	Star ±3.75°, ±11.25°
Secondary	2 x delta, 2 x star
Impedance voltage (between primary-secondary)	15% at 774 V, 59.2 MVA
Insulation level	
Primary	395 kV AC
Primary neutral point	160 kV AC
Secondary	4 kV AC
Tertiary	25 kV AC
BIL, Primary	900 kV
Cooling system	FOA

Fig. 3 shows the connection diagram of this transformer.

This transformer has tap windings and on-load tap changers. Wide voltage adjustment is performed by changing

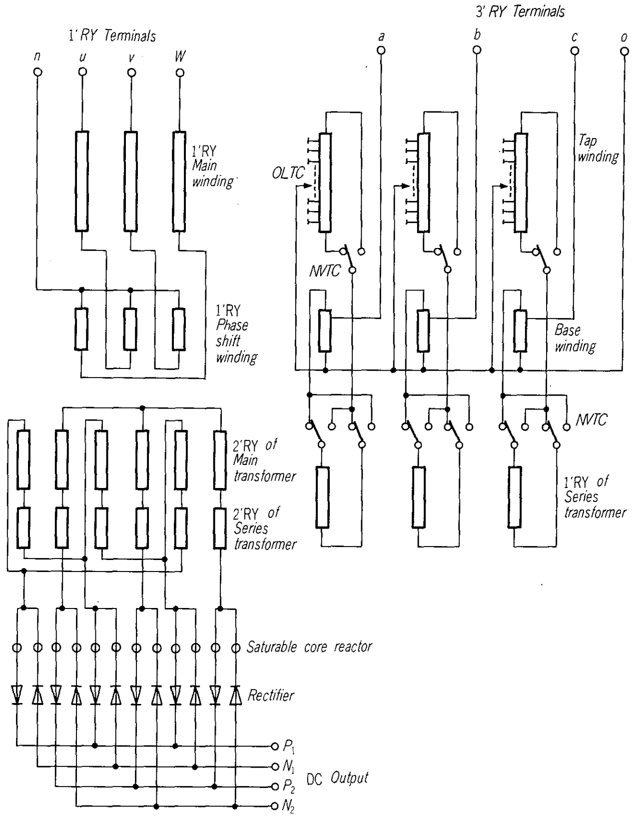

Fig. 3 Transformer connection diagram

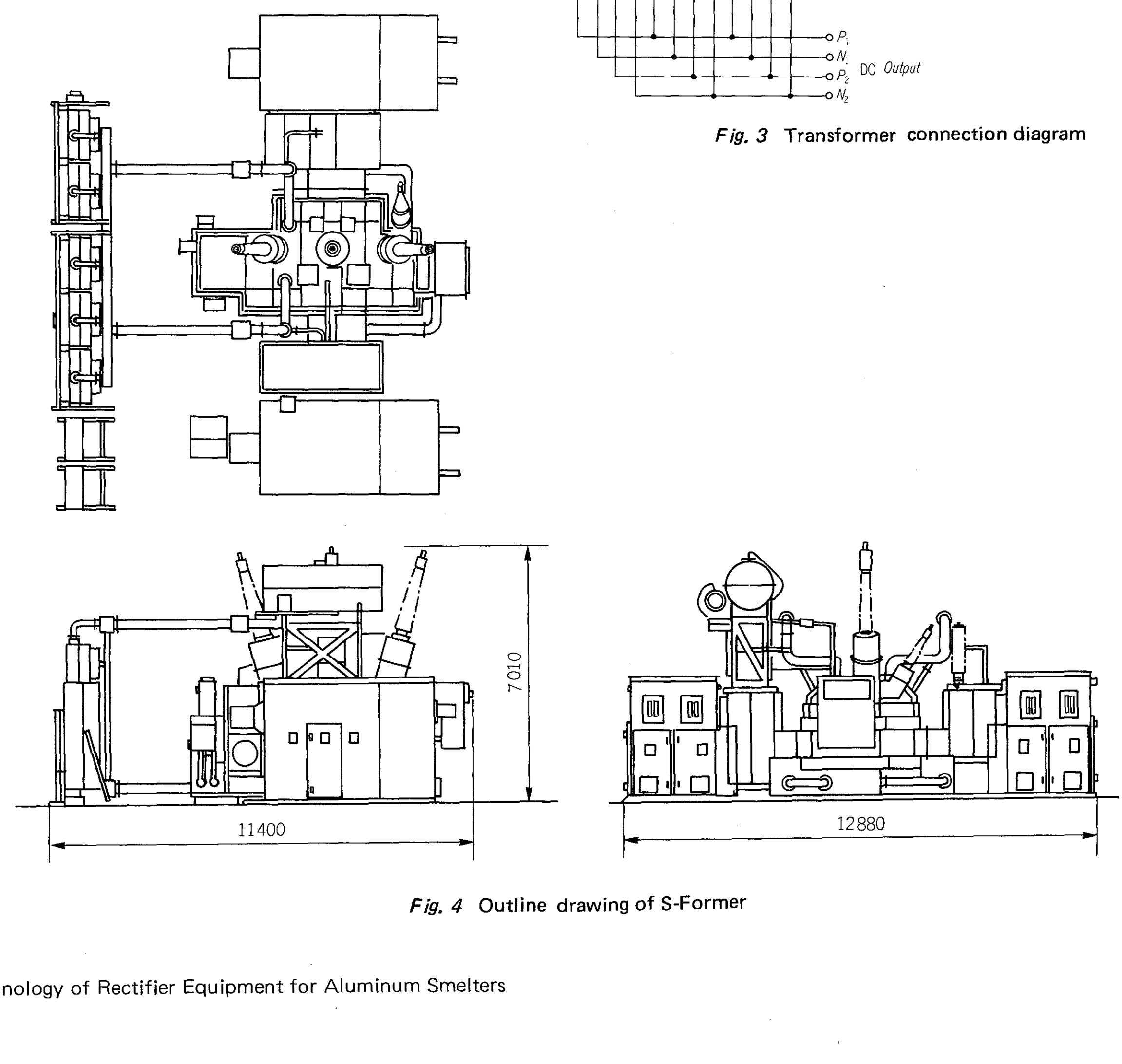

Fig. 4 Outline drawing of S-Former

the magnetizing voltage of the internal booster transformer. Momentary, rapid load changes caused by the anode effect are controlled by saturable reactors.

As outstanding features compared with power transformers, rectifier transformers need low voltage windings with large current carrying capacity, wide voltage adjustment range and the phase shift winding required for higher harmonic suppression.

Since the phase shift winding is installed at the high-voltage side and its construction is much complicated, the insulation was designed on computer-aided analysis for high reliability.

Since the low-voltage windings are composed of multiple parallel high current windings, current balance among them and therefore losses were much improved.

A static shield between the primary and secondary was provided to protect the low-voltage winding and rectifier against surge voltage transferred from the high-voltage side.

(2) Rectifier Assembly

Rated capacity	51,520 kW
DC output voltage	920 V
DC output current	56,000 A
Connection	Three-phase double way
Cooling system	FWA

The rectifier uses flat type diodes having a good cooling efficiency and a direct water-cooling system which cools diodes and heat sinks by circulating deionized water. For a more compact construction and for good access under outdoor installation conditions, walk-in type cubicle are adopted.

This walk-in type cubicle provides excellent air-tightness and not only increases reliability by preventing the entry of corrosive gasses, but also eliminates the need to crate the equipment for shipment and simplifies installation work.

Fig. 4 is an outline drawing of this S-Former.

III. THYRISTOR RECTIFIER

1. Outline of the system

The thyristor rectifiers which commenced operation at Martin Marietta Aluminum (USA) in December 1981 is outlined below.

Potline rating	950 V, 120 kA, 114 MW
Number of rectifier units	4
Unit rating	950 V, 40 kA, 38 MW
Pulse number	48 pulses with four units in operation.
Primary input voltage	23 kV, 60 Hz
Harmonic filter	60 MVAR

Fig. 5 is the skeleton diagram of this equipment. *Fig. 6* is its outline drawing.

The harmonic filter is designed to maintain the unity power factor at receiving point (230 kV) and to suppress the higher harmonic current flowing into the network for I.T product being less than 2800. It is a high pass filter tuned at the frequency of 11th order of the fundamental.

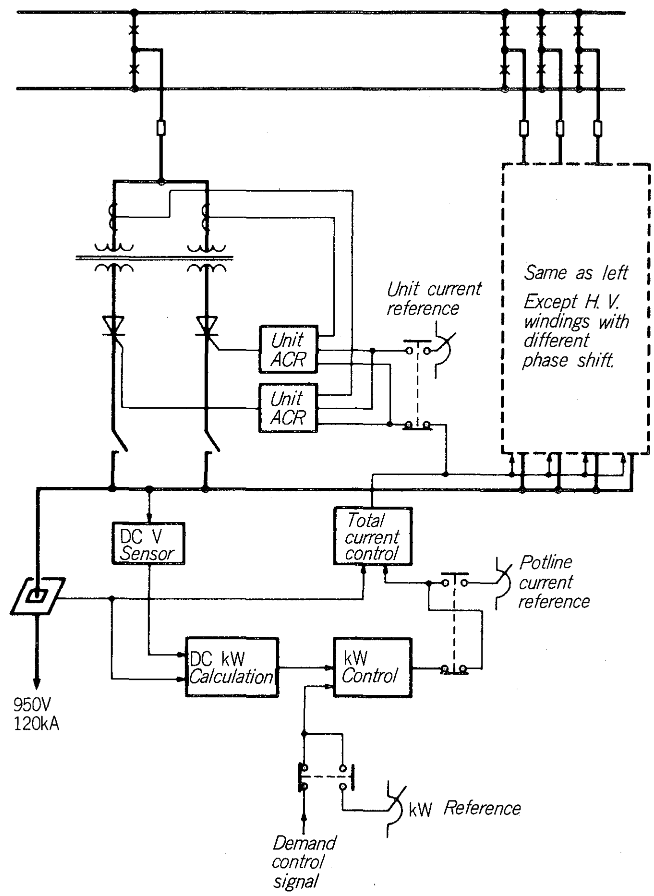

Fig. 5 Arrangement and control scheme of thyristor rectifier

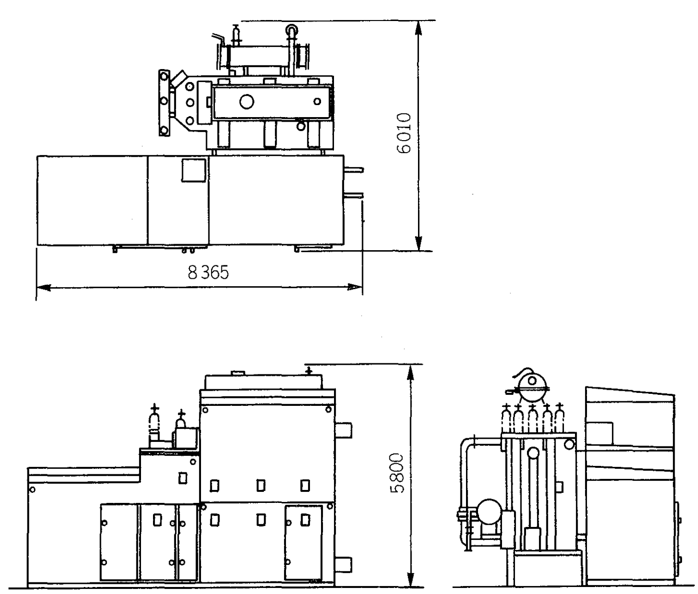

Fig. 6 Outline of S-Former

The conversion efficiency is 99.0% with four units in operation at 950 V 120 kA.

2. Features of thyristor rectifier

(1) This rectifier equipment consists of four units of 950 V, 40 kA thyristor rectifiers. The ability to supply 120 kA full load current even when one unit is out of service applies to this system. From the standpoint of higher harmonic suppression this rectifier equipment also has a 12 pulse configuration for each unit and the fifth and seventh higher harmonic currents are suppressed. This configuration has the following features. The rectifier transformer as well as rectifier assembly has a two-stories construction which minimizes the magnetic coupling between delta and wye group windings, reduces the cross current caused by the voltage phase difference between two groups and eliminates the need for an interphase transformer.

The reason behind this is that when 12 pulse system is produced by operating two groups of six pulse rectifiers having a 30° phase difference in parallel, the difference of the instantaneous output voltage between the six pulse rectifiers causes a cross current to flow. Output voltages ed1 and ed2 of each six pulse rectifier in the circuit of *Fig. 7* are as shown in *Fig. 8* and this difference voltage produces a ripple in each DC current as shown by id1 and id2. As can be seen from *Fig. 8*, this cross current is determined by the magnitude of the DC output voltage, magnitude of the control delay angle and impedance of the circuit through which the cross current flows.

In aluminum smelting, rectifier output voltage is comparatively high and thyristor delay angle becomes large especially in starting-up procedure, therefore the cross current becomes fairly large. When this cross current is large,

a. Loss increases.

b. Control becomes unstable because the current is intermittent at low output current.

c. Local heating occurs in the structure near the DC conductors.

Therefore, it should be suppressed to about 20-30% of the rated current. One method of achieving this is to insert an intephase reactor or DC reactor in the DC output circuit. However, this is disadvantageous in large current circuit from the standpoints of economy and efficiency. On the other hand, in this transformer-rectifier unit, the delta group and wye group transformers and rectifiers are separated from each other in a common tank and in one enclosure, to make the impedance large enough to suppress the cross current.

(2) To improve the low power factor operation during smelter start-up, 100-95-90-85-80-75% no-voltage taps are provided on the rectifire transformer. Further more, a 60 MVAR harmonic filter bank is installed to

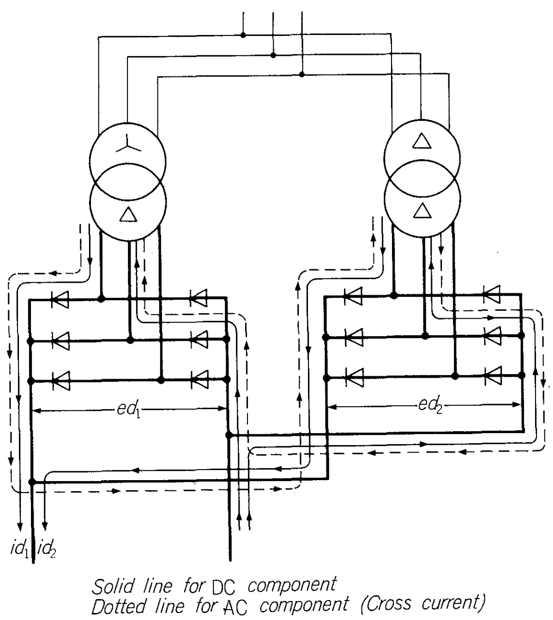

Fig. 7 12 pulse rectifier circuit arrangement and cross current

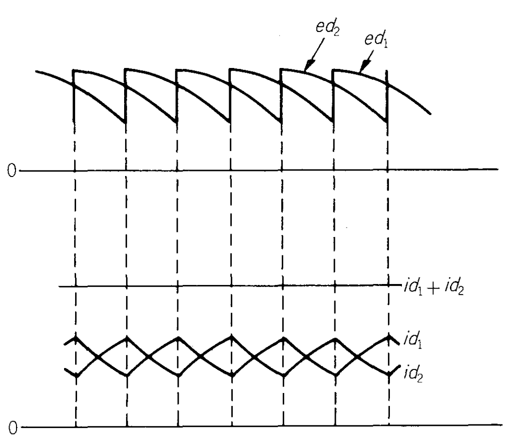

Fig. 8 Wave form of output voltage and current in 12 pulse system

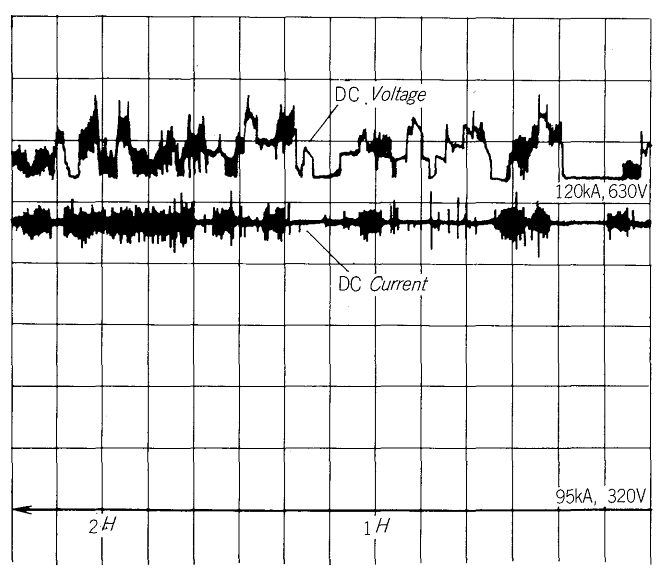

Fig. 9 Chart of potline current and voltage

keep a unity power factor at the receiving point.

(3) Each six pulse group has an automatic current regulator (ACR) which keeps the current at a preset value.
As an outer control loop, either total current control or kW control can be selected. If kW control mode selected, constant kW control or demand control is possible as indicated in *Fig. 5*.
The potline current and voltage during actual operation are charted in *Fig. 9*.

IV. COUNTERMEASURES FOR REDUCING HIGHER HARMONICS

In recent large capacity smelting plant which consumes an electric power exceeding 150 MW, the rectifier system will be designed to make more than 36 pulse number from the view point of higher harmonics. Furthermore, to reduce lower component such as 5th and 7th which will be generated in N-1 units operation, each unit will be designed to make twelve pulse system, thus producing 12 x N pulse system per bank, in many cases. In this case, a cross current which circulates between the 6 pulse commutating group exists as described in section 3.2.

To suppress this current to within the allowable limits an ample impedance is necessary. This impedance is given by the sum of the rectifier internal impedance and the impedance of the external DC bus (between the 6 pulse commutation group). To obtain this impedance economically, countermeasures at the equipment side, such as the insertion of an interphase reactor, etc., is not necessarily a good policy and a study on increasing the impedance by making refinements in the arrangement of the external DC conductors is also important.

V. POSTSCRIPT

Two examples of rectifier equipment using the newest technology were introduced.

The authors hope that the description will be of assistance to plant engineers in future planning.