UDC 621. 314. 22 : 382. 6

RECENT TRANSFORMERS WITH MODERN FEATURES FOR THE EXPORT MARKET

By Shigeaki Kunieda
Shoichi Hattori
Tadaaki Fujimoto
Chiba Factory

I. INTRODUCTION

The efforts of Fuji Electric Co. are based on an active attitude in respect to transformer export and directed toward the development of new techniques to meet the high efficiency, high quality, and low cost required of transformers destined for the export market. As a result of these efforts, Fuji has overcome stiff international competition and has exported over a total of 1500 Mva of Fuji power transformers alone. In recent years, Fuji has recorded a continuous export in such industrial fields as furnace and rectifier transformers.

Furthermore, the superiority of Fuji's extra-high voltage techniques and the high quality of Fuji transformers have been recognized. The order for three 1ϕ, 300 Mva 525 kv autotransformers received from the United States has gained wide attention. These transformers are currently being manufactured.

Ranking among the largest industrial transformer in the world are four 37,000 kva silicon rectifier types now beeing manufactured for installation in Australia.

Fuji Electric is continuing to devote its efforts towards the development of further techniques to meet the requirements of its foreign customers.

Points that must be considered in the manufacture of transformers destined for export, which are not encountered for those destined for the domestic market, are as follows:

(1) Problems concerning standard specifications or different application conditions.

(2) Problems concerning shipment.

Generally, ASA, NEMA, BS, or AS standards must be met by transformers destined for export. Fuji transformers meet these standards.

In addition, transformers manufactured by Fuji Electric are designed with the utmost care so as to satisfy all conditions, from hot tropical climates to cold northern climates.

Another problem encountered with transformers manufactured for export is that of shipment. There are some cases in the domestic market area in which shipment of the transformers must be done by sea. However, the requirements for shipment of transformers overseas are much stricter than those for domestic delivery. Consideration has been given to this point in the construction of Fuji transformers. The problems inherent in the shipment of transformers overseas and an introduction to the transformers manufactured by Fuji Electric for the export market, as well as the new techniques developed by Fuji Electric are given below.

II. STANDARDS

Generally, ASA or BS standards are used for transformers destined for the export market. However, when designing and manufacturing these transformers, consideration must be given to such problems as climatic conditions, special applications, ambient temperature variations and difference in maintenance procedures.

The differences between ASA and BS standards and the JEC 168 standards used in Japan are listed in *Tables 1* and *2*. *Table 1* is a comparison of JEC, BS, and ASA temperature rise standards while *Table 2* is a comparison of JEC, BS, and ASA test voltage standards. In addition to the above, difference in the impulse voltage waveform and impulse voltage test methods must also be considered.

***Table 1* Temperature Rise Limit of Oil-Immersed Transformer**

Standard			JEC	BS	ASA
Winding Temperature Rise (deg)	Natural oil circulation		55	60	55
	Forced oil circulation (forced oil-water cooling)		60	65 (70)	55
Oil Temperature Rise (deg)	When indirect contact with atmosphere		55	50	55
	When direct contact with the atmosphere		50	50	50
Ambient Temperature (°C)	Air	Maximum	40	40	40
		Daily average	35	30	30
		Yearly average	20	20	—
	Water	Maximum	25	25	30
		Daily average	—	20	25

Table 2 Comparison List of Test Voltage

			Impulse Test Voltage					Power Frequency Test Voltage				
JEC			JEC		BS			JEC		BS		
Nominal voltage (kv)	Insulation class (Go or No.)	BIL (kv)	Not solidly grounded system	Solidly grounded system	Not solidly grounded system	Solidly grounded system	ASA (kv)	Not solidly grounded system	Solidly grounded system	Not solidly grounded system	Solidly grounded system	ASA (kv)
3.3	3	45	45		50		60 75 95	16		16		19
6.6	6	60	60		75		75 95 110	22		22		26
11	10	90	90		95		95 110	28		28		34
					110					38		
22	20	150	150		150		150	50		50		50
33	30	200	200		200		200	70		70		70
					250		250			95		95
					300					115		
66	60	350	350		350	300	350	140		140	115	140
77	70	400	400					160				
(110)	80	450		450	450	380	450		185	185	150	185
110	100	550	550		550	450	550	230		230	185	230
(154)	120	650		650	650	550	650		275	275	230	275
154 (187)	140	750	750	750	750	650	750	325	325	325	275	325
(220)	170	900		900					395			
275	200	1050		1050	1050	900	1050		460	460	395	460

III. SHIPMENT

Although it is important to satisfy the customers specifications when designing the transformer, the problem of shipment limitations must be considered first. For this reason, conditions such as transportation from the port of unloading to the actual installation site, method of transportation, and weight and dimension limitations are checked beforehand.

The conditions imposed when shipment is made by sea are much stricter than those of other shipment methods because of meteorological and oceanographic

Table 3 Frequency of Acceleration in Vibration during Shipment

Transformer		Ship		Maximum Transformer Acceleration in Vibration		
Capacity (Mva)	Shipping weight (ton)	Total tons (ton)	Dimensions L×W×D (m)	Vertical direction (g=980cm/sec²)	Traverse direction (g=980cm/sec²)	Advancing direction (g=980cm/sec²)
172.5	205	917	64 × 9.5×5.45	0.24 g	0.15 g	0.15 g
28	4×49.5	3600	92.21×13.6×6.4	0.125 g	0.257 g	0.004 g
20	2×45	610	48.8 × 8.2×5.6	0.405 g	0.19 g	0.075 g
80	150	450	47.8 × 7.7×—	0.28 g	0.33 g	0.11 g
230	205	497	48.76× 8.5×4.3	0.054 g	0.28 g	0.235 g
150	125	650	44.51× 7.8×3.8	0.112 g	0.075 g	0.01 g
345	240	653	57.55× 9 ×4.4	0.35 g	0.35 g	0.09 g
35 2×7.5	63 2×13	498	51.52× 8 ×4	0.31 g	0.15 g	0.07 g
50 10	58 20	690	61 × 9.2×4.6	0.78 g	0.5 g	0.07 g
265	179	495	55.6 × 8.5×4.1	0.198 g	0.259 g	0.057 g

conditions. In the case of domestic shipment, the ship can take shelter in a nearby port if the meteorological and oceanographic conditions become too bad. However, this is almost impossible for shipments going to foreign markets. For this reason, careful selection of the ship as well as complete negotiations with the shipping firm concerned are required before actual shipment is made.

In recent years, Fuji has been conducting measurements of acceleration in vibration incurred during shipment of transformers. The results of these measurements are listed in *Table 3*. During the design of the transformer, investigations are made to ascertain whether the following two points will satisfactorily prevent damage due to acceleration in vibration during shipment.

(1) A supporting device placed between the core and winding and the tank.

(2) A supporting device placed between the entire transformer and the side of the ship.

IV. BRIEF DESCRIPTION OF VARIOUS TRANSFORMERS

The following is a brief description of the specifications, construction, and features of the power and industrial transformers recently manufactured for export.

1. India (Koyna Hydroelectric Project, Stage II)

(1) Specifications:

Single-phase 50 cps OFW no-voltage tap-changing transformer (12 units).

Rating: Continuous
Standard: BS
Capacity: 30 Mva
Voltage: $11\,\text{kv}/\frac{252}{\sqrt{3}}-\frac{240^{R}}{\sqrt{3}}$ kv
BIL: 95 kv/900 kv
Connection: △/⅄
Impedance: 12.5% (30 Mva Base)
Weight: Total weight: 49,000 kg
Core and winding weight: 32,500 kg
Oil: 10,000 liters
Overall dimensions: Length: 5.8 m
Width: 2.9 m
Height: 5.0 m

Fig. 1 is an external view of the transformer undergoing the work test.

(2) Construction and features.

A broad outline sectional view of the transformer is shown in *Fig. 2*. As shown in *Fig. 2*, a part of the lower tank supports the windings and, simultaneously, secures the lower core yoke. Employment of this method permits a reduction in the quantity of oil required, eliminating the use of a box type lower frame, and a reduction in the cost of the transformer. The tank is designed, as much as possible, to be of the circular type to reduce tank stiffener and improve vacuum test strength.

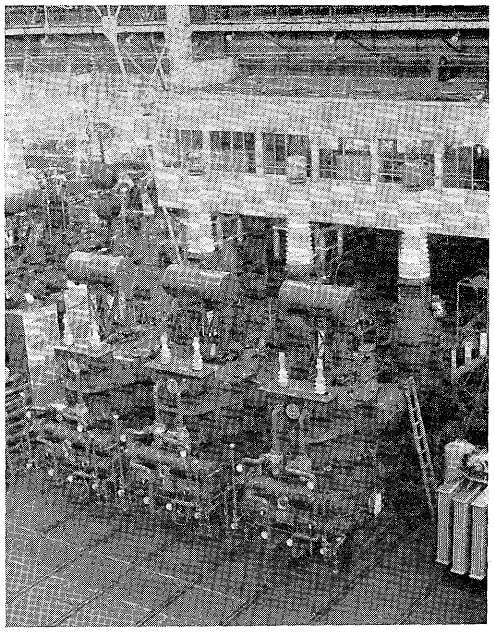

Fig. 1 30 Mva transformer under testing

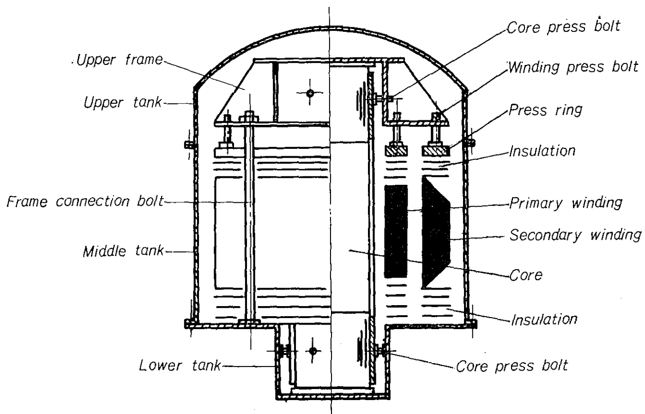

Fig. 2 Section of core and winding

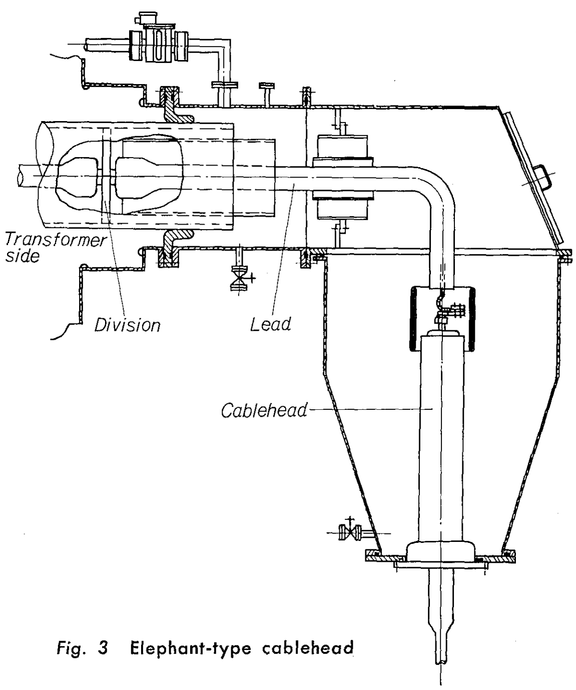

Fig. 3 Elephant-type cablehead

Windings are cylindrically arranged with the secondary winding on the outside and primary winding on the inside. Oscillation-free cylindrical layer winding, which is standard construction for extra-high voltage windings, is employed for the secondary winding.

The terminal at the secondary winding side has elephant-type construction. This construction is shown in *Fig. 3* and has been especially developed by Fuji Electric. The elimination of the draw-through bushing in oil and reasonable insulation arrangement have resulted in a very compact sized elephant-type cablehead.

2. Taiwan (Taiwan Power Co.)

(1) Specifications:

Special three-phase 60 cps FOA on-load tap-changing transformer with no-voltage taps.

Rating: Continuous
Standard: ASA
Capacity: 120/120/40 Mva
Voltage: (161–154^R–147^F) kv ± 7.5%/69 kv/11 kv
BIL 650 kv/350 kv/110 kv
Connection: 人/人/△
Impedance: P–S: 11.5% (120 Mva base)
S–T: 6.2% (120 Mva base)
P–T: 19.8% (120 Mva base)
Weight: Total weight: 208,000 kg
Core and winding weight: 94,000 kg
Oil: 51,600 liters
Overall dimensions: As shown in *Fig. 4*

Fig. 5 is an external view of the transformer during work test.

(2) Construction and features

This transformer has various unique technical features, one of which is the so-called "special three phase" construction employed due to shipping limitations. In three phase construction, the transformer is divided into three parts, a single common flange is positioned on the three separated tanks to fill the adjoining flanges; at the same time, a tank cover is placed on the common flange and the three flanges are bolted. By doing this, even a very high voltage, large capacity transformer can be easily settled, and the time required for erecting the transformer at the site can be reduced.

The core is designed so as to be of center leg construction from a standpoint from transportation limitations. By a special steel sheet joint of the yoke and outside leg so that core inside surface becomes flat, reduction of magnetic mean length and weight are obtained. Core and windings arrangement is shown in *Fig. 6*.

The windings are arranged cylindrically with the primary tap winding at the extreme outside, and the primary, secondary, and tertiary winding in this sequence. Standard multi-cylindrical tap winding is

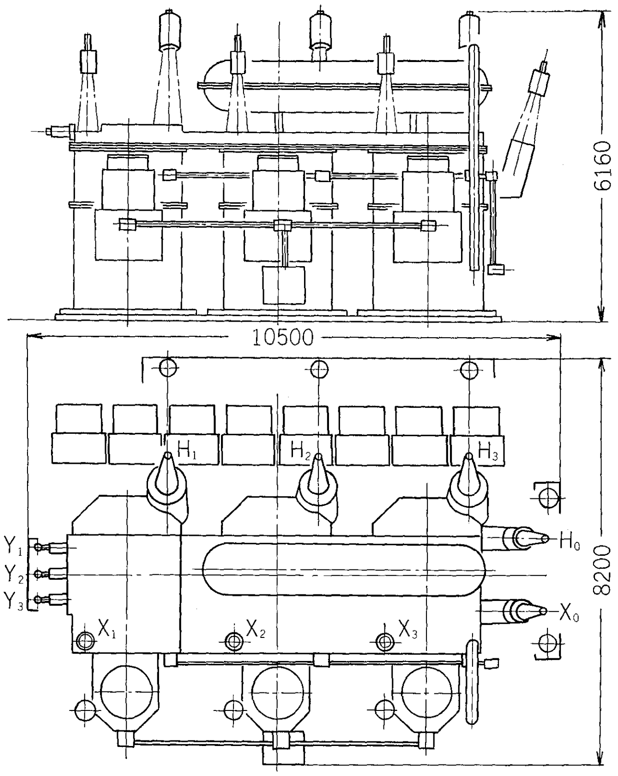

Fig. 4 Outline of 140 Mva transformer

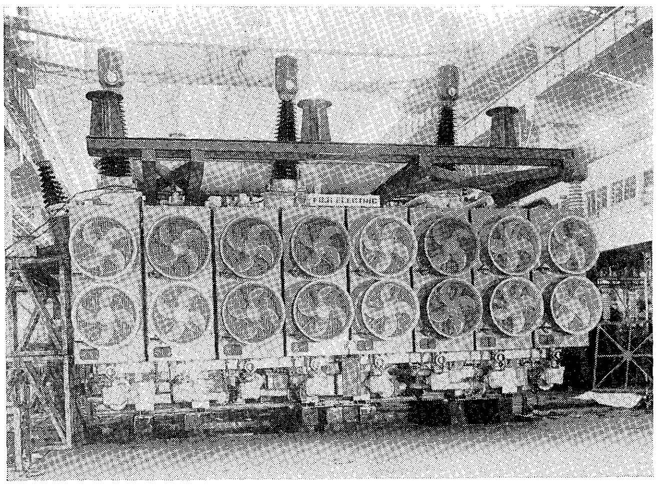

Fig. 5 140 Mva on-load tap-changing transformer

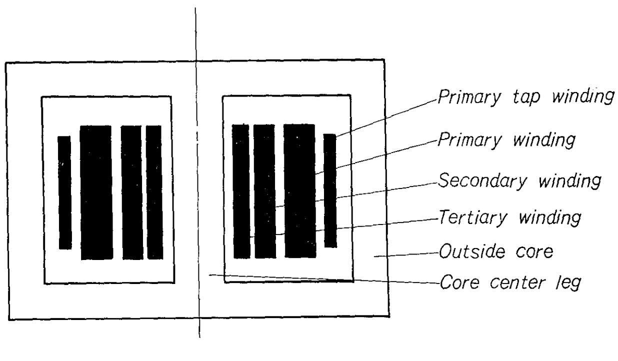

Fig. 6 Arrangement of core and windings

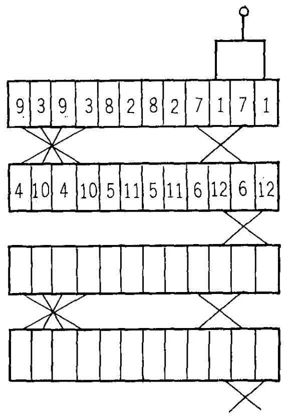

Fig. 7 Special interleaved disk type winding

employed for the primary tap winding, and special interleaved disk type winding for the primary main winding. A number of parallel conductors are combined in the special interleaved disk type winding construction.

In the special interleaved disk type winding, the parallel conductors are alternately arranged and connections are inserted between the conductors having the large potential difference (refer to *Fig. 7*). Thus, this type of construction greatly increases the series capacitance between turns. As a result, $\alpha=\sqrt{c/k}$ (where c=capacitance to ground and k=series capacitance) which determines the initial voltage distributions and largely influences the voltage oscillation occurring subsequent to initial voltage distribution, and is greatly reduced thereby improving the impulse voltage performance characteristics.

When the number of parallel conductors is increased, application to a large capacity transformer can be made by arranging the conductors in such a way as to position a single conductor vertically or by dividing the conductors into four groups with each group positioned differently.

This special interleaved winding has already been applied to a considerably large number of transformers having a BIL greater than 350 kv and favorable results have been achieved. Disk winding is employed for the secondary winding while multi-parallel winding is used for the tertiary winding.

Leakage flux distribution is calculated by digital computer to reduce stray load losses. The conductor size is determined according to the leakage flux distribution and is aimed at the reduction of eddy current losses. Furthermore, the use of silicon steel sheets to shield the tank wall and of non-magnetic metal for the portion adjoining the winding, such as a clamp, greatly reduces the load losses. The primary winding has on-load and no-voltage taps to extend the tap-changing range required by the customer. The on-load tap-changer is a standard DSCI type and is shipped with a tap-changer for each phase built into the tank. This eliminates the work required to install the tap lead at the site. The motor-driven operating mechanism is one and is driven by a common shaft.

The forced-oil forced-air cooling system employs a standard UF type radiator. To make the cooler compact, a large cooling fan having a high air flow and low noise level is employed.

3. Australia (The Electricity Trust of South Australia)

(1) Specifications

Three-phase 50 cps, OFB/ON on-load tap changing transformers (Two units)

Rating:	Continuous
Standard:	AS, BS
Capacity:	120 Mva (OFB)/60 Mva (ON)
Voltage:	275 kv/66 kv $+15\%$ -5%
BIL:	1050 kv/350 kv
Connection:	See *Fig. 8*
Impedance:	17.5% (120 Mva base)
Weight:	Total weight: 230,000 kg
	Core and windings: 91,000 kg
	Oil: 61,000 liters

Overall dimensions (including separated) radiators:

Length: 19.6 m

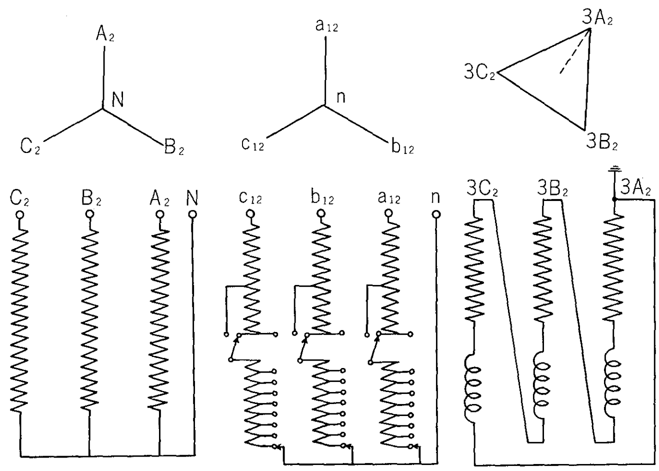

Fig. 8 Connection diagram

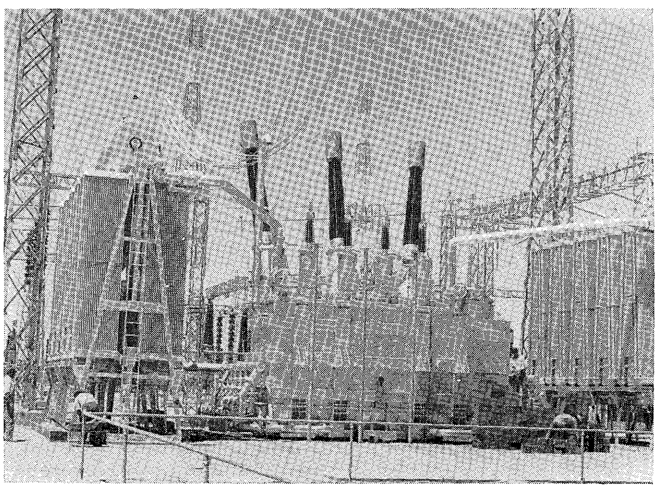

Fig. 9 120 Mva on-olad tap-changing transformer

Width : 8.2 m
Height : 9.9 m

The installed transformer is shown in *Fig. 9*.

(2) Construction and features

The windings are cylindrically arranged from the outside with the primary winding, secondary winding, secondary tap winding, and stabilizing winding. An oscillation-free cylindrical layer winding, which has been producing favorable results as extra-high voltage windings, is employed for the primary winding. At the same time, a cylindrical winding is employed for the secondary winding, multi-parallel cylindrical tap winding for the secondary tap winding, and multi-parallel winding for the stabilizing winding. A current-limiting reactor is connected in series to increase the zero sequence impedance ; this is done to meet the requirement that the zero sequence capacity be limited to 300 Mva (5 sec). The current-limiting reactor is mounted under the on-load tap changer to improve the space factor inside the tank.

Because the voltage regulation of this transformer is made at the secondary side (low voltage side) a switching current of 1050 amp is necessary. However, this requirement has been fully satisfied by using the standard 3DSCI type on-load tap-changer already developed for large capacity transformer applications. An external view of the standard 3DSCI type on-load tapc-hanger appears in *Fig. 10*.

An external view of the radiator appears in *Fig. 11*. The radiator, having a 60 Mva natural cooling capacity, is mounted on each side of the transformer.

To increase the radiation effect during natural cooling, either a slight head between the radiator and transformer or a thicker connection pipe between the radiator and transformer is employed. The radiator used is that employed in the oil-immersed natural air cooled transformer. The cooling fan is installed on the bottom so that air flow is from bottom to top. Furthermore, the radiator is positioned diagonally and an air guide used to increase the radiation efficiency during forced-air cooling. Oil pumps, along with a spare pump, are installed on the main transformer. Switching between the operating pumps and spare one is done automatically; hence the oil pump circuit includes a no-return valve to prevent the return flow of oil.

Transportation of the transformer in Australia was made on a 150-ton trailer of the Electricity Trust of South Australia (see *Fig. 12*).

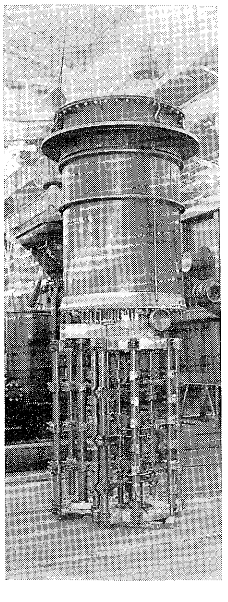

Fig. 10 3 DSCI type on-load tap-changer

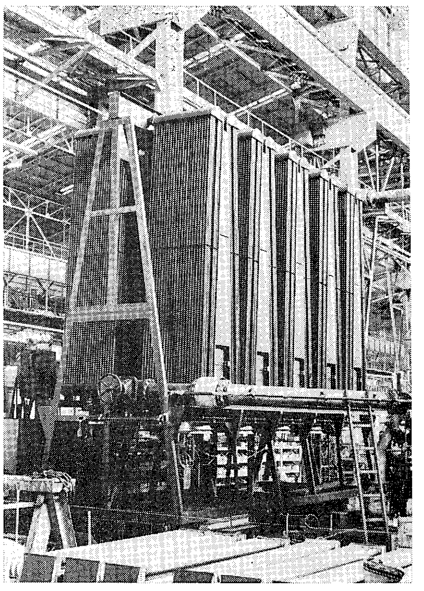

Fig. 11 Separated radiator

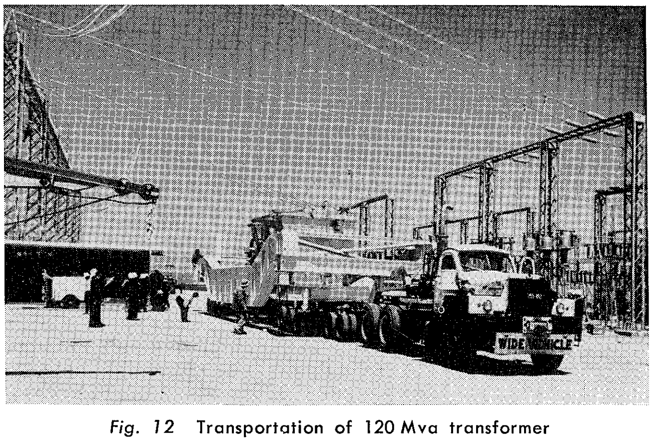

Fig. 12 Transportation of 120 Mva transformer on trailer in Australia

4. United States (Bonneville Power Administration) (Under manufacture)

(1) Specifications

Single-phase 60 cps, FOA on-load tap-changing autotransformer (3 units)

Rating	Continuous
Standard	ASA
Capacity	300/300/25 Mva
Voltage	$\frac{525 \pm 4 \times 6.25}{\sqrt{3}}$ kv/$\frac{241.5}{\sqrt{3}}$ kv/34.5 kv

BIL	1425 kv/650 kv/200 kv
Connection	Refer to *Fig. 13*
Impedance	P–S 10% (300Mva base)
	S–T 27% (300Mva base)
	P–T 40% (300Mva base)

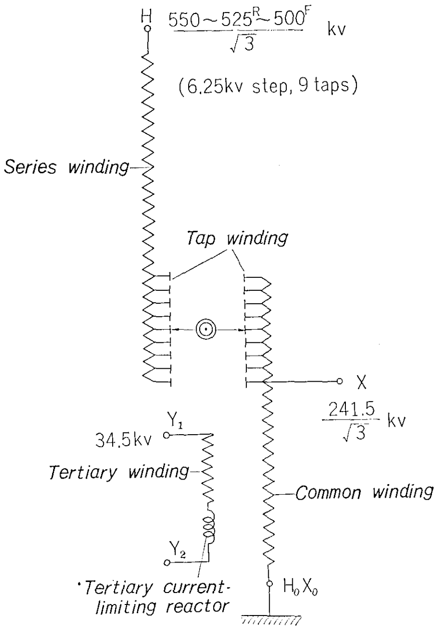

Fig. 13 Connection diagram of 300/300 /25 Mva autotransformer

(2) Construction and features

Transformer capacity is 900 Mva in a three-phase bank and is referred to as one of the largest in the world. Since this is the largest transformer that has been manufactured by Fuji Electric, the highest attention is being paid and the latest techniques are being used. The core is of two leg construction formed by two lines of core sheets divided into left and right sides by a center duct. Because the core has no bolt holes, it is clamped by passing the bolt through the center duct. The diameter of the core is very large and thus, in addition to bolt clamping, resin-impregnated glass-fiber bands are wound around the core to form a single core form. Since these bands support the ends of the core sheets, vibration and noise are reduced.

The windings are arranged coaxially with the tertiary winding at the core side and then the common winding, tap winding, and series winding in this sequence. The series and common windings employ oscillation-free cylindrical layer windings since this type of winding is best suited for extra-high voltage use. Static shield plates are provided at the line ends of the series and common windings, as well as between the tap windings in order to improve the surge performance and suppress voltage oscillations of the tap winding. Transposed conductor is employed for both the series and common windings. (This is shown in *Fig. 14*.) This is done to reduce the conductor size and thereby decrease eddy current losses in windings. The time required for manufacture of the winding is also reduced.

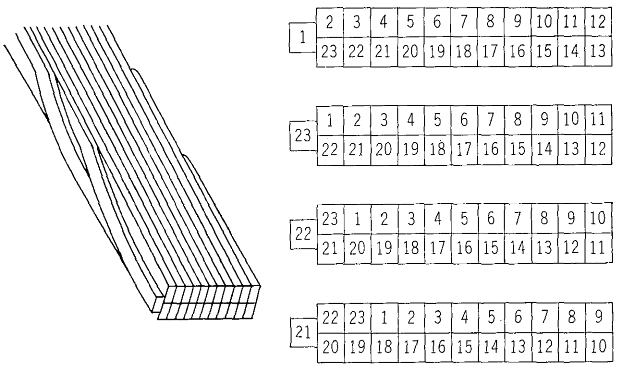

Fig. 14 Transposed conductors

The corona test, as well as other ordinary impulse and low frequency voltage tests, is required. The corona discharge level should not exceed the specified level, especially during the low frequency test subjected for two hours with a voltage of 1.5 times the normal voltage $\left(550\text{ kv}\times\frac{1}{\sqrt{3}}\times1.5=475\text{ kv}\right)$ to ground.

For this reason, all measures to make this transformer completely free from corona, such as relieving the electric field concentration at high voltage parts, strict selection of insulation materials, as well as complete drying and oil impregnation of insulation materials and elimination of voids in insulation materials, have been taken.

5. Carbide Furnace Transformer for China

(1) Specifications

Three-phase 50 cps, FOW on-load tap-changing carbide furnace transformer.

Rating	Continuous
Standard	JEC
Capacity	35,000 kva
Primary voltage	35,000 v
Secondary voltage	248～220(R)～157 v
	3.5 v step, 27 taps
Secondary current	91,800 amp
Connection	Primary : 人 or △
	Secondary : 人
	Tertiary : △
Impedance voltage	5.8% (35,000 kva base)
Weight	Total weight : 101,000 kg
	Core and windings : 52,000 kg
	Oil : 31,000 liters
Overall dimensions	Length : 6.6 m
	Width : 5 m
	Height : 5.85 m

(2) Construction and features

An external view of the furnace transformer is shown in *Fig. 15*.

The main transformer windings are arranged, from the core side, with tertiary, primary, and secondary winding. The primary winding is made of disk winding and the tertiary winding is made of two layers of multi-cylindrical tap windings. Since the

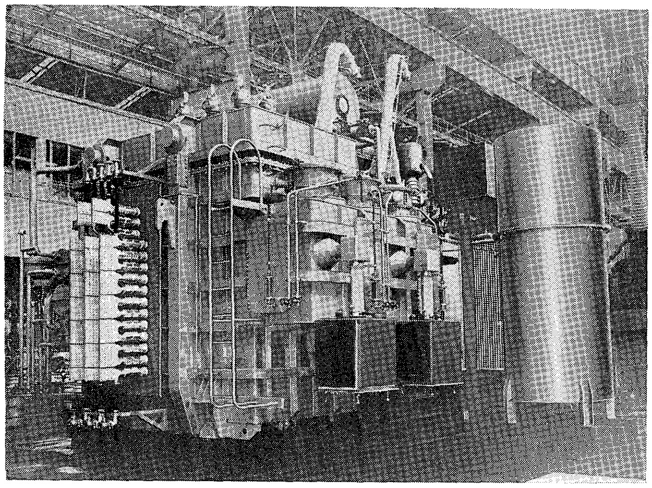

Fig. 15 Furnace transformer

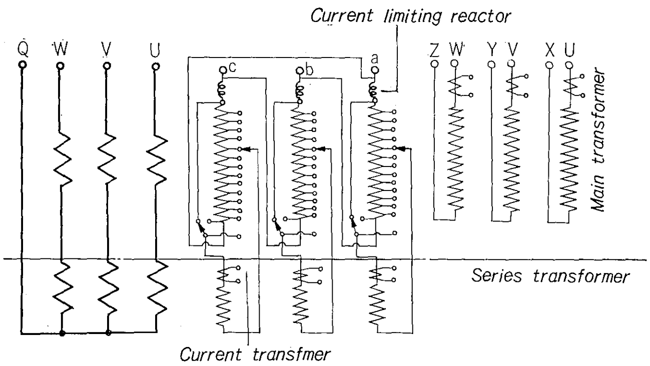

Fig. 16 Connection diagram

secondary winding passes a current of 91,800 amp, a single copper plate having especially high conductivity is employed. In addition, a continuously wound " figure 8 " type ring coil, developed by Fuji Electric, is used for the main and series transformers. As shown in *Fig. 16*, the voltage can be adjusted in either the positive or negative directions by the reversing switch of the tertiary winding circuit. Moreover, a tap voltage of 11.47 kv is led out of the tank and connected to a power capacitor to improve the power factor of the primary side. (Connection of 6000 kva capacstor is possible.) It should also be mentioned that a current limiting reactor is used to protect the tertiary winding from short-circuits at the previously mentioned power capacity.

A more accurate measurement of the secondary current of the main transformer, as well as automatic regulation of the electrode, can be made by inserting a current transformer into the primary circuit of the series transformer and measuring the transformer primary current.

The on-load tap-changer is designed so that the secondary voltage can be adjusted either individually for each phase or for all three phases at the same time.

The secondary circuit includes especially developed water-cooled terminals. The distance between the water-cooled terminals is made as short as possible to reduce the reactance. The terminal is made of copper pipe and is cooled by the water passing inside the pipe. The copper pipe construction never allows the cooling water to leak into the insulation oil.

6. Dc 120 v, 16,000 amp Silicon Transformer-Rectifier for Copper Electrolysis at Copper Refineries Pty Ltd. (Australia)

(1) Specifications

Three-phase 50 cps, OFW with on-load tap-changer

Rating: Continuous
Standard: NEMA TR-1 IEC PUB. 146
Rated output; 1920 kw
Rated ac voltage: 11,000 v
Rated dc voltage: 120 v
Rated dc current: 16,000 amp

Transformer specifications

Rated capacity: Ac side: 2305 kva
Dc side: 2 × 1630 kva
Tertiary side: 25 kva*
Rated voltage: Dc side: 117.9(R)~42.7 v
3.76v step, 21 taps
Tertiary voltage: 415 v*
Connection: Ac side: △
Dc side: 人 Y
Tertiary side: 人

* Tertiary windings are equipped to be used as the power source for auxiliary equipment.

Interphase reactor (contained in the transformer)
Rated voltage: 47 v
Rated current: 8000 amp

Voltage control reactor (contained in the transformer)
Maximum control voltage: Dc 15 v
Rated current: 4610 amp

Silicon rectifier
Components: Number of series: 1
Number of parallel: 18
Number of poles: 6
Type of silicon element: Si 250-3
Number used: 108

Weight: Total weight: 35,300 kg
Core and windings: 15,000 kg
Oil: 10,800 liters

Overall dimensions: Length: 5.35 m
Width: 3.83 m
Height: 4.4 m

(2) Construction and features

By connecting the ac power source to the ac side of this equipment, the desired low dc voltage and large current desired can be obtained. The dc voltage is lower and the voltage control range is greater than that of the furnace transformer.

The construction is quite similar to that of the furnace transformer. *Fig. 17* is an external view of the silicon transformer-rectifier. The transformer is composed of the main and series transformers as mentioned in the section on the 35,000 kva carbide

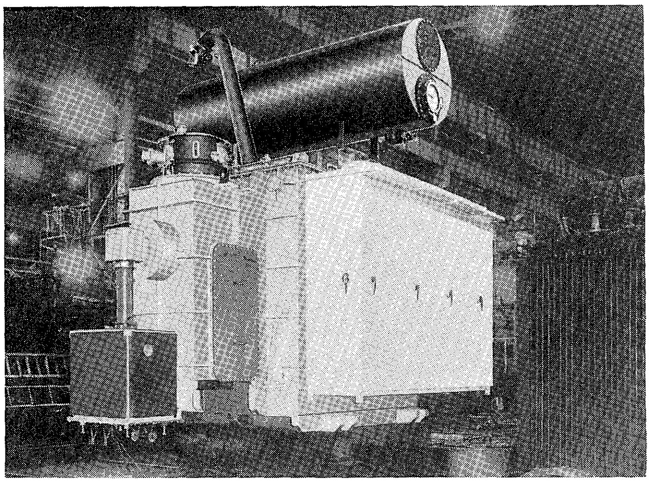

Fig. 17 Silicon transformer-rectifier

furnace transformers. The series winding is of the " figure 8 type ", which is a strong construction against mechanical forces, and constitutes a double star connection. The transformer contains inter-phase and voltage control reactors. Careful attention has been given to the leads at the dc side, which carry a large current, to reduce both the lead reactance and stray load losses. Coarse adjustment of the transformer dc voltage is accomplished by the on-load tap-changer while fine adjustment is automatically made by the self-contained voltage control reactor. Equipment connection is shown in *Fig. 18*.

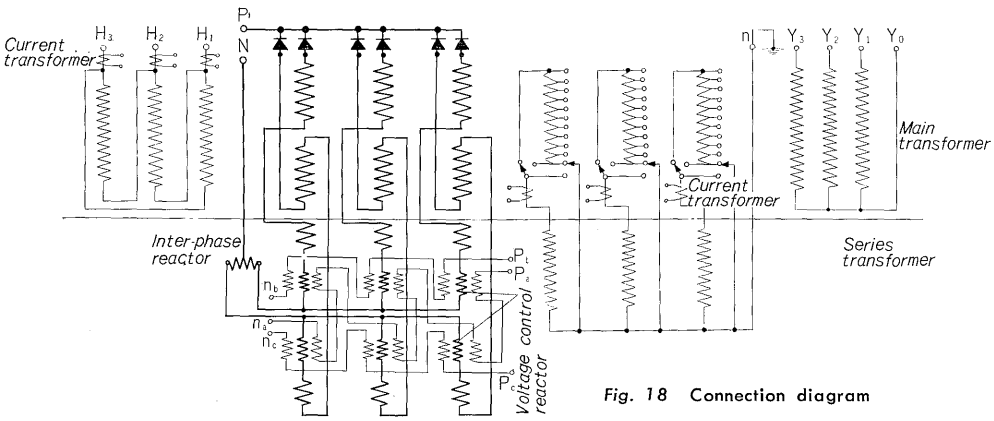

Fig. 18 Connection diagram

7. Dc 600 v, 160,000 amp Silicon Transformer-Rectifier for Aluminum Electrolysis, Alcan Australia (Under Manufacture)

(1) Specifications

Three-phase 50 cps, OFA with on-load tap-changer (4 units)

Rating:	Continuous
Standard:	BS, IEC
Rated output:	4 × 32,000 kw
Rated ac voltage:	132 kv
Rated dc voltage:	600 v
Rated dc current:	4 × 53,400 amp

Transformer ratings

Rated capacity: Ac side: 37,000 kva
Dc side: 4 × 9250 kva
Tertiary: 11,000 kva

Rated voltage: Ac side: 132(R) kv $^{+5\%}_{-2\times 5\%}$, with ±7.5° phase regulation
Dc side: 490(R) v ~ 53 v (54 taps)
Tertiary: 10,860 v

Connection: Ac side: 人 with neutral solidly grounded
Dc side: two units 4 × 人 Bridge connection
two units 4 × △ Bridge connection
Tertiary: Y

Voltage control reactor
Max. control voltage: dc 45 v
Rated current: 7700 amp

Silicon rectifier
4 sets × 1 (number of series) × 24 (number of parallel) × 6 (number of poles) = 576
Silicon rectifier element: Si 250–3

(2) Construction and features

This transformer-rectifier has silicon rectifiers mounted on each side of the tank to obtain direct electrical and mechanical unification between the transformer and rectifier. Highly advanced techniques, referred to as S-former, originally developed by Fuji Electric have been incorporated into this transformer. This transformer is now being manufactured by concentrating all the Fuji Electric techniques listed below.

(a) This S-former directly receives its voltage from 132 kv high-voltage network and dc output controlled in a wide range can be obtained from the output terminal. An example of the connection of a single unit from among the four units is shown in *Fig. 19*.

Since a record-breaking 132 kv direct step-down system is employed for this class of silicon transformer-rectifier, new techniques have been employed to protect the silicon rectifier from surge voltage.

(b) This silicon transformer-rectifier has a single unit capacity of 37,000 kva (output: 32,000 kw) and a total weight, per unit, of 180 tons.

(c) The dc output voltage can be optionally controlled in the 0 to 600 v range. Therefore, an indirect voltage regulation system is employed with the voltage control reactor housed inside the S-former tank.

(d) Each unit is phase-shifted alternately and complete 24-phase rectification with minimum harmonics is performed.

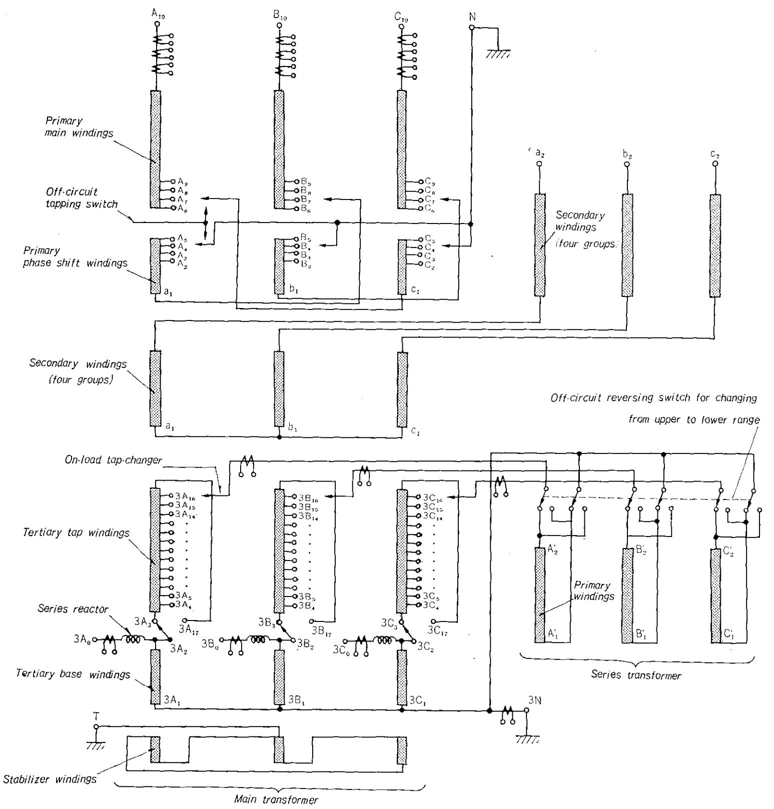

Fig. 19 **Connection diagram of transformer-rectifier**

(e) An extremely economical system (our patent) is constructed and the power factor and harmonic absorption are improved by connecting the power capacitor bank and series reactor to the tertiary circuit to control the voltage of the main transformer.

(f) Dc side winding employs a "figure 8 type" ring coil, which has a favorable space occupation factor as well as mechanical strength. Furthermore, a specially developed method (Fuji patent), which cancels the magnetic flux mutually induced by the leads, is employed. This reduces the reactance and stray load losses and effectively protects the structual body from local heat.

(g) The silicon rectifier and protection fuse of this S-former are threaded into the bus bar, which is cooled by the forced insulation oil of the transformer, and the generated heat is carried away by the oil, making a completely enclosed cubicle possible. The cubicle is therefore completely isolated from the surrounding atmosphere. Accordingly, if this transformer is installed outdoor, the cooling oil is re-cooled with a forced-oil air-cooled heat exchanger. Since cooling water is not used, this transformer is maintenance free and both the initial costs and operating costs are minimized.

V. CONCLUSION

Fuji Electric has been supplying a large number of transformers to both the domestic and exports markets ever since the construction of one of the largest and most modern transformer manufacturing plants in the world was completed in a corner of Tokyo Bay in 1962. This factory has a pier which can berth ships of approximately 10,000 tons and handle the loading of equipment weighing up to 500 tons. Hence, even the largest transformers can be supplied from this factory.

When reviewing the present world power supply situation, it can be seen that fairly remarkable progress has been made, especially with the actualization of 500∼750 kv extra-high voltage transmission. The efforts of Fuji Electric are being directed toward the development of new techniques in the manufacture of the transformers required for this extra-high voltage transmission. Fuji Electric hopes to contribute to the development of the world's power supply by manufacturing low cost, highly efficient and reliable transformers.