Fuji Electric

Innovating Energy Technology

Fuji S-Former

AC to DC Power Conversion System for Electrolytic Services

04A1-E-0001

S-Former Complete Systems
Fuji's wealth of experience

Fuji Electric engineers, designs, manufactures and supplies complete AC to DC power conversion systems (Fuji S-Formers) for industrial electrolytic services which require a large amount of DC power.
The installed capacity of Fuji S-Formers supplied to date amounts to over 20,890MW (as of February 2009).
Fuji designs and manufactures both rectifier transformers and rectifier assemblies under one roof at its ISO 9001 and 14001 certified Substation Equipment Factory.
The rectifier transformers and rectifier assemblies are designed and manufactured as a system under one coherent quality control system. Prior to shipment, the rectifier transformers, rectifier assemblies and associated controls are coupled at our factory and tested as a system.
The combined test is our standard factory test procedure, which is a unique feature of our quality control system.
Fuji Electric designs and manufactures the diode and thyristor devices for S-Formers at our Matsumoto Factory. The Matsumoto Factory, also ISO 9001 and 14001 certified, is equipped with the most advanced semiconductor manufacturing facilities and is one of the largest semiconductor factories in Japan. We are proud of the extremely high-reliability of the Fuji diodes and thyristors manufactured there, as proven by the overall statistical failure rate stated on the following pages.

S-Former for outdoor installation, 1,330V DC, 85kA, 113.05MW

N99-2491-1

Contents

Features of S-Formers

Maximum safety and reliability
Fuji S-Formers are designed for maximum safety and reliability. The S-Former embodies our experience in manufacturing over 19,628MW of power conversion units.

Design flexibility
Fuji Electric can supply equipment conforming to the principal world standards such as IEC, ANSI, NEMA, CSA, BS, AS etc., as well as the special requirements of the customer.

System coordination
Fuji Electric can supply a total power conversion system in coordination with the power system of the customer to assure optimum performance. This includes transformers, rectifiers, controls, harmonic filters, switchgear and auxiliary equipment.

In-phase contra-polarity connection
Fuji Electric's patented "in-phase contra-polarity connection" provides the following outstanding features:
- High-efficiency and power factor
- Increased unit ratings
- Balanced current

Combination test at our Factory
Prior to shipment, Fuji Electric conducts a combination test at our factory with the transformer, rectifier and control actually coupled. Fuji S-Formers are thus proven for design and performance as a system before shipment. This is a unique feature of our total quality control system.

Highly reliable Fuji diode and thyristor devices
High-reliable Fuji diodes and thyristors are proven by the overall statistical failure rate of as low as 0.012% per year in over 30 years of operating experience.

Wide-range voltage control
The diode rectifier systems can easily and economically provide a wide-range voltage control by employing an optimum combination of on-load tap-changer and saturable reactors. The thyristor rectifier systems ensure smooth stepless control from zero to rated voltage by thyristor gate control.

Ease of maintenance
Special attention is given to ease of maintenance when designing the equipment. Fuji rectifiers feature a walk-in enclosure with ample space for maintenance inside.

Fuji power semiconductors

DK10940

Outline of S-Formers

Fuji Electric's manufacturing experience

Fuji Electric is one of the world's leading suppliers of AC to DC power conversion systems. Fuji S-Formers benefit from the technical and manufacturing expertise that Fuji Electric has built up over many years of manufacturing various types of power conversion equipment since the era of mercury arc rectifiers, contact converters and selenium rectifiers.

Fuji S-Former is a close-coupled type transformer-rectifier unit which incorporates various patented features developed by Fuji Electric, and is ideally designed to meet the power requirements of electrolytic services. Fuji S-Formers use an "in-phase contra-polarity connection" system developed by Fuji Electric, the special features and merits of which are described on the following pages. This special system enables the S-Formers to be rated as high as 230kA per unit at 500V DC using a single-way connection and up to 115kA per unit at 2,000V DC with a double-way connection.

Fuji S-Formers are highly regarded for their excellent technical features and performance. Installed capacity to date totals 22,659MW or 38,544kA DC.

Fuji S-Formers are designed with flexibility and versatility to satisfy each customer's special requirements and to meet the various standards and regulations. Many S-Formers have been exported to overseas markets and are acquiring a high-reputation for their excellent performance under many different operating conditions.

Fuji Electric has its own representatives and local agents in various areas of the world.

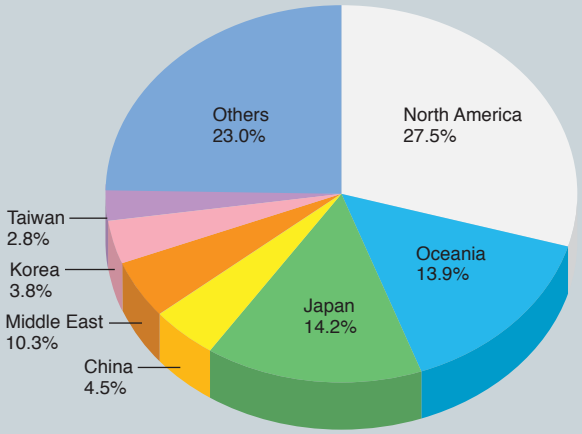
This sales and service network provides Fuji Electric's customers with access to the latest information on the Fuji S-Formers. Competent supervising engineers are available upon request for overseas installation, testing and commissioning.

Supply record of Fuji S-Formers

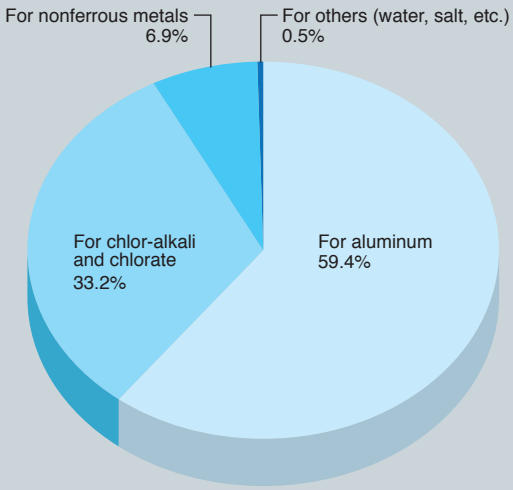
Large output MW	Direct step-down
131.25MW, 105kA, 1250V	**220kV/1750V DC**, 87.5kA
184.0MW, 92kA, 2000V	**220kV/2000V DC**, 92.0kA
99.75MW, 133kA, 750V	**132kV/1450V DC**, 82.5kA
Large current	**Multiple output**
155kA, 165V	**8 × 16.2kA**, 425V
150kA, 250V	**4 × 30.3kA**, 520V
133kA, 750V	

Fig. 1 Supply records (1959 to February 2012)
Amount in kW: 22,659MW

(1) Destination



(2) Application



Long-life diodes and thyristors

Reliability of Fuji power semiconductors

The diodes and thyristors used in Fuji S-Formers are manufactured in our Matsumoto Factory, which is one of the largest semiconductor factories in Japan. These power semiconductors are made under carefully controlled environmental conditions with testing and checking at each stage of manufacture including the purchasing and procurement of materials and parts, the manufacturing process and throughout the final inspection. Fuji Electric's diodes and thyristors have exceptionally high-reliability, as proven by the extraordinary low-failure rate of approximately 0.012% per year in over 30 years of operational experience. And we're still working hard to raise this reliability level even higher.

Voltage ratings
Fuji Electric has been supplying diodes and thyristors rated up to 5,000V (peak reverse voltage), and even higher ratings can be supplied. Fuji Electric's diodes and thyristors are designed with an ample creepage distance between anode and cathode thus assuring reliable performance at various voltages.

Current ratings
Fuji Electric's diodes and thyristors can carry as much as 3,500A of continuous forward current and have a high-overload capacity.

Table 1 shows the ratings of typical diodes and thyristors used for S-Formers.

Table 1 Ratings of diodes and thyristors

Semiconductors	Model type	Mean forward current [A]	Peak reverse voltage [V]	Technical document No.
Diode	ER3501FL-50	3500	5000	MT5C8461
	ER3001FL-45	3000	4500	MT5C8446
	ER2501FL-37	2500	3700	MT5C8269
	ER3201FL-30	3200	3000	MT5C8406
Thyristor	EG2003FL-30	2000	3000	MT5E1677
	EG1503FL-30S	1500	3000	MS5E0196
	EG1503FL-25	1500	2500	MS5E0187
	EG2003FL-16	2000	1600	MT5E1492

DK10964

Fuji power diodes and thyristors DK10941

Close-coupled S-Formers

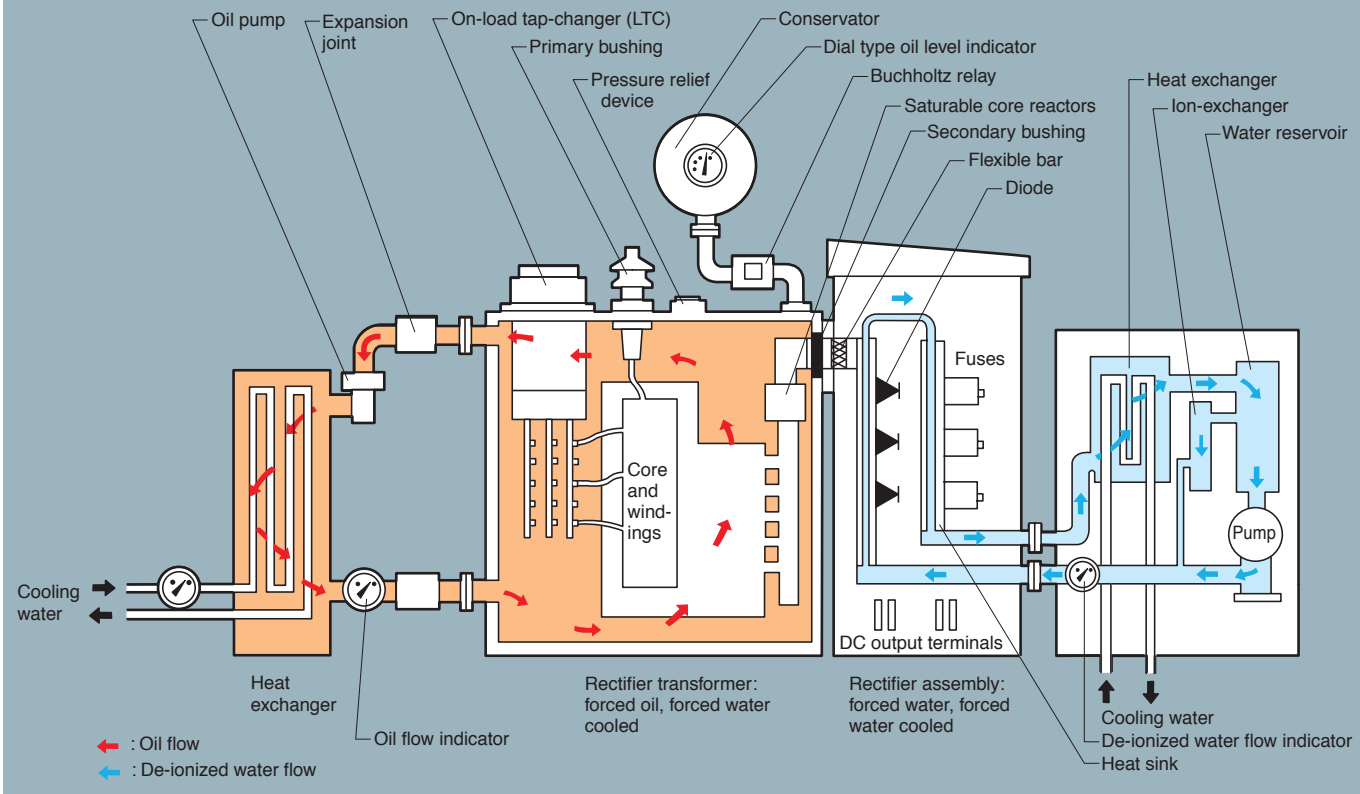
with high-unit rating, reliability, long-life expectancy and versatility

Diode S-Formers

Close-coupled S-Formers are designed to supply the DC power requirements of a typical aluminum reduction plant, chlor-alkali plant and other electrolytic services.
The S-Formers are composed of a rectifier cubicle and a rectifier transformer. The rectifier cubicle and transformer are assembled separately and then connected together by short flexible bars thus forming close-coupled S-Formers.
The rectifier is cooled by a cooling system such as WFWF (forced water, forced water), WFAF (forced water, forced air), AFAF (forced air, forced air) or AF (forced air) depending on the customer's requirement of each particular application.
The cooling system of the transformer is either OFWF (forced oil, forced water) or OFAF (forced oil, forced air).
The S-Formers are available in many different sizes up to a maximum DC output of 1,500V (double-way) or 250kA (single-way).

Diode S-Former, 33kV AC/1,130V DC, 55kA DK10965

Fig. 2 Conceptual arrangement of close-coupled diode S-Former



Thyristor S-Formers

Thyristor S-Formers have basically the same construction as the close-coupled diode S-Formers except that thyristors are used in place of diodes. The thyristor S-Formers have become almost predominant in chlor-alkali plant and electrolytic copper refinery applications.
The thyristor S-Formers do not require an on-load tap-changer (LTC) and saturable reactor, so maintenance is easy.
The thyristor S-Formers are available for the same ratings as diode S-Formers.

Thyristor S-Former, 69kV AC/407V DC, 147kA A600965

Thyristor S-Former, 11kV AC/365V DC, 4 × 10.8kA N99-1729-7

Inner view of diode rectifier DK10966

Cooling systems

Transformer cooling

The optimum cooling type to be used is selected taking into consideration the amount of heat to be removed, special conditions at the installation site and other requirements of the customer. The following cooled types are commonly used.

(1) Forced oil circulation
(a) OFWF (forced oil, forced water) cooled type
・Shell and single tube type oil to water cooler with oil pump, or
・Shell and double tube type oil to water cooler with oil pump
(b) OFAF (forced oil, forced air) cooled type
(c) Forced oil self cooled type: Panel radiator with oil pump

(2) Natural oil circulation
(a) OA (oil immersed, self) cooled type
(b) FA (oil immersed, forced air) cooled type

Among the above cooling systems, OFWF and OFAF are widely used. In the case of a large rectifier transformer having multiple windings, the forced oil cooled system is essential. Cooling oil passage ducts are provided in the core and winding through which cooling oil circulates to remove the heat.
OFWF is most effective for a compact and space-saving transformer.

OFAF (forced oil, forced air) cooled transformer and WFAF (forced water, forced air) cooled rectifier A600138

Rectifier cooling

Various cooling systems are available as shown below for the rectifier assembly. Fuji Electric will suggest the cooling system best suited to the customer's particular needs.

(1) Water cooled
(a) WFWF (forced water, forced water) cooled type
(b) WFAF (forced water, forced air) cooled type

(2) Air cooled
(a) AF (forced air) cooled type
(b) AFWF (forced air, forced water) cooled type
(c) AFAF (forced air, forced air) cooled type

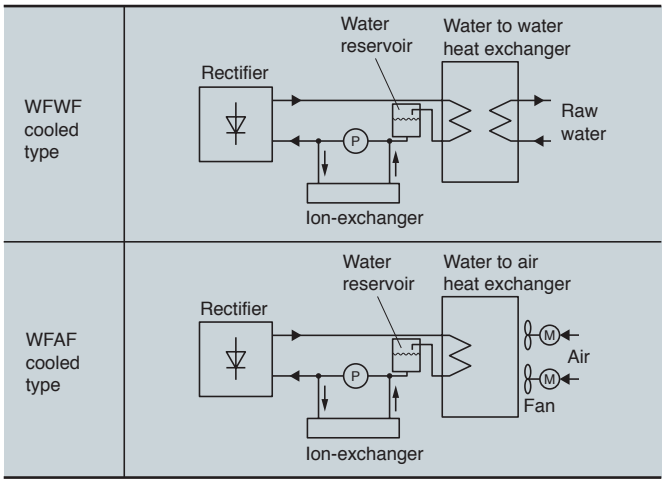
WFWF (forced water, forced water) cooled rectifier N89-2056-28

AF (forced air) cooled rectifier N89-3059-6

Water cooled rectifiers

Water is the most effective cooling media in practice. In case of Fuji Electric's water cooled rectifiers, de-ionized water is used for the primary cooling media, which is circulated through the heat sinks to remove the heat generated by the diodes or thyristors.
The de-ionized water warmed up after circulating in the heat sinks is then cooled by a WFWF (forced water, forced water) or WFAF (forced water, forced air) heat exchanger.
In order to maintain sufficiently high-resistivity of the de-ionized water, some portion of the circulating de-ionized water is continuously bypassed through a cartridge type ion-exchanger provided in the cooling system. Its resistivity is maintained at over $10^6\Omega$-cm and is continuously monitored by a conductivity meter in the system. De-ionized water tubes are connected between heat sinks. The tubes are made of a cross-linked polyethylene material which is particularly durable both mechanically and thermally.
The de-ionized water circuit is carefully designed so as to avoid electrolytic corrosion in the system and to keep the water temperature uniform in the different heat sinks.

Fig. 3 Water cooled rectifiers

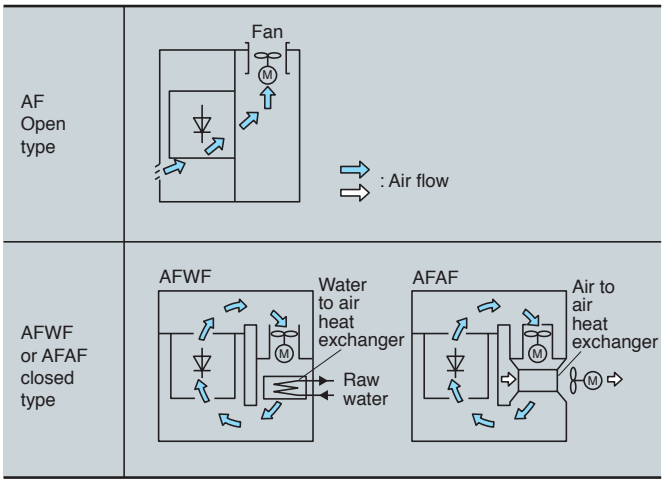


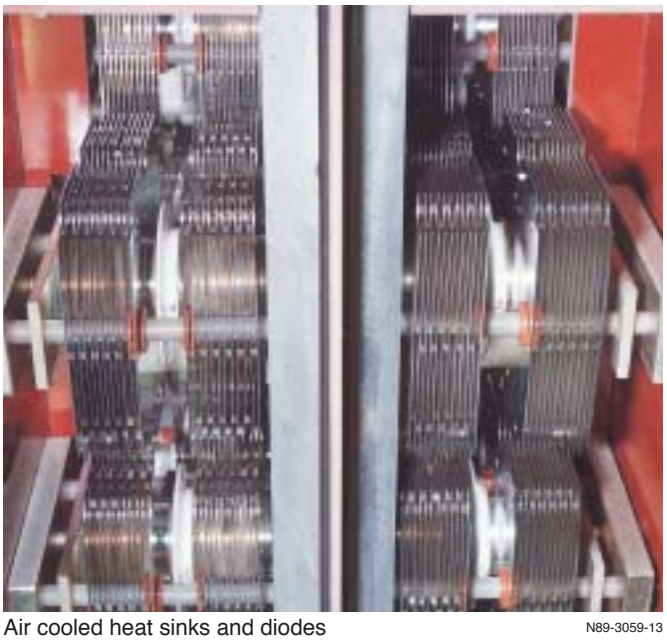
Water cooled heat sinks and diodes DK10967

Air cooled rectifiers

The AF cooled open type is the simplest of all forced air cooled rectifiers. This rectifier type is designed for indoor installation where filtered and well-convected cooling air is available.
AFAF is suitable for rectifiers for outdoor installation where industrial cooling water is not available.

Fig. 4 Air cooled rectifiers





Air cooled heat sinks and diodes N89-3059-13

In-phase contra-polarity connection

with excellent performance, minimizes local heating, improves power factor, simplifies diode/thyristor current balance

Some of the difficulties encountered in designing and manufacturing large power conversion equipment are as follows.
(a) Local heating due to large current
(b) Increase of reactance drop at secondary circuit of transformer causing a low-power factor
(c) Current unbalance among different diode/thyristor devices

These have been regarded as inherent problems with large current rectifiers. Fuji Electric's "in-phase contra-polarity connection" system solves these problems.
The features of the system are explained using a simple 3-phase Star (Y) connection.

Fig. 5 shows rectifier circuit of a simplified conventional 3-phase Star connection for explanation. Fig. 6 shows rectifier circuit of the simplified in-phase contra-polarity Star connection.

Fig. 5 Simplified open Star connection

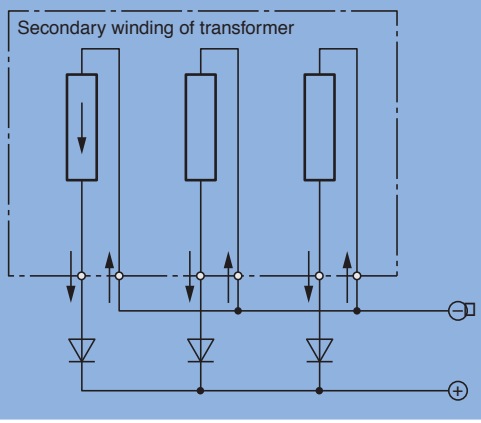
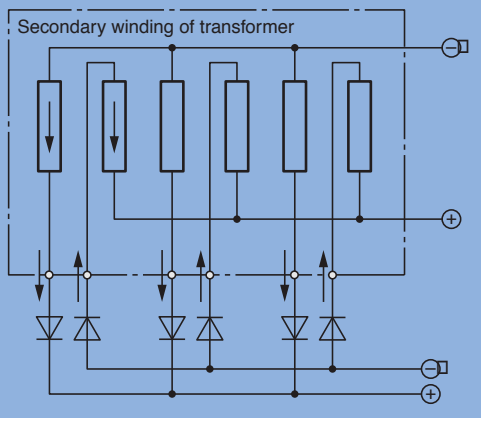


Fig. 6 Simplified in-phase contra-polarity Star connection



In Fig. 5, the secondary bushings of the transformer are positioned close to each phase, and the star connection is made outside of the transformer tank. Only local heating near the secondary bushing is reduced with this construction.
To solve all the problems described above, Fuji Electric designed and patented the "in-phase contra-polarity connection" system.

In Fig. 6, the transformer windings of each phase are brought out in parallel to form a path of the rectifier circuit with opposing current flows to each other. Fig. 7 shows the physical arrangement of this construction.

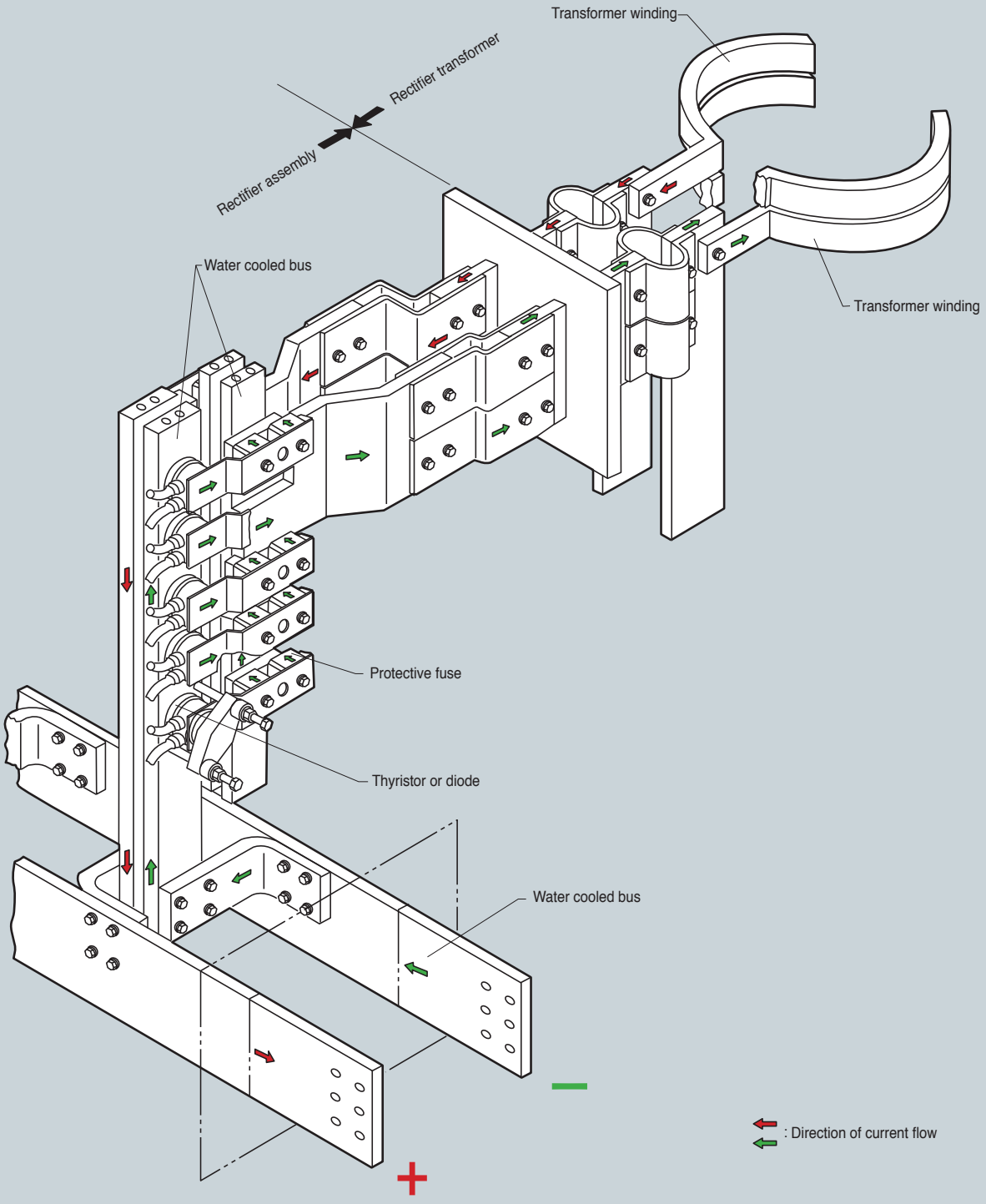
Features of the "in-phase contra-polarity connection" construction are as follows.

(1) Local heating
In case of the construction of Figs. 5 and 6, stray magnetic flux and its heat loss are negligible small on the surface of the transformer tank where the transformer bushings are brought out.
In Fig. 6, stray magnetic flux and its heat loss are also reduced in the circuit between the transformer and rectifier. As a result, robust carbon steel can be used for the rectifier cubicle enclosure, instead of non-magnetic material used for the construction of conventional connections.
In Fig. 6, the sectional area of the transformer bushings can be reduced to half of that with the conventional connection.

(2) Reactance drop
As a result of (1) above, a reactance drop over the circuit between the transformer and rectifier in the rectifier cubicle can be neglected, so a high-power factor can be obtained.

(3) Current unbalance among diodes/thyristors
Current unbalance occurs due to a difference in reactance value in the circuit that connects the diodes/thyristors and transformer.
In case of the conventional connection shown in Fig. 5, the circuit requires a forced balance reactor to reduce the current unbalance, and complicated analysis must be repeated for determining the value of the forced balance reactor at the design stage.
The construction shown in Fig. 6 requires no such forced balance reactor.

Fig. 7 Physical arrangement of "in-phase contra-polarity connection" circuit



Wide range of voltage control

on-load tap changing, stepless salurable core reactors, off-load range changing

Electrolytic processes of aluminum, magnesium and zinc require a wide range of voltage control. The diode rectifier transformers for such services are equipped with the following voltage control functions.

(a) On-load tap-changer provided on tap winding for automatic incremental voltage control
(b) Saturable core reactors provided in transformer tank for automatic stepless voltage control
(c) Off-load tap-changer provided on tap winding for wide range of voltage range change-over

Fuji Electric offers the ideal voltage control system to suit the particular process using a combination of these functions.
Figs. 8, 9 and 10 show typical voltage control systems.
Fig. 8 shows the voltage control system which controls collectively multiple units of S-Formers with one common voltage regulating transformer equipped with an on-load tap-changer.
In the system shown in Fig. 9, each of the 6 pulse rectifier units is equipped with an on-load tap-changer (occasionally an off-load tap-changer as well) and thus the output voltage of each rectifier unit is controlled individually.
Fig. 10 shows a rectifier system comprising 12 pulse units with each unit consisting of a voltage regulating transformer and 12 pulse rectifier transformers accommodated in the common tank.

Fig. 8 Voltage control system, with one common voltage regulating transformer

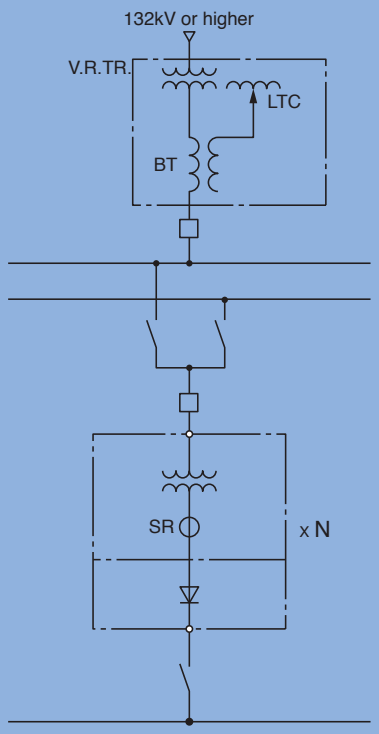


Fig. 9 Voltage control system, with 6 pulse rectifier units

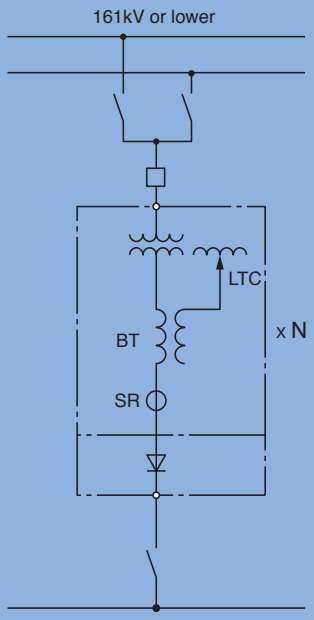
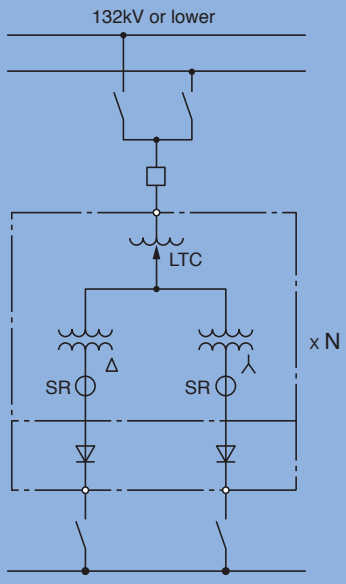


Fig. 10 Voltage control system, with 12 pulse rectifier units



V.R.TR. : Voltage regulating transformer
LTC : On-load tap-changer
BT : Voltage boosting transformer
SR : Saturable reactor

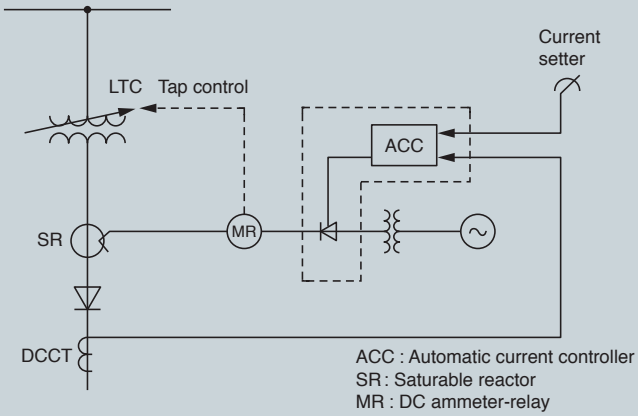
Current control systems

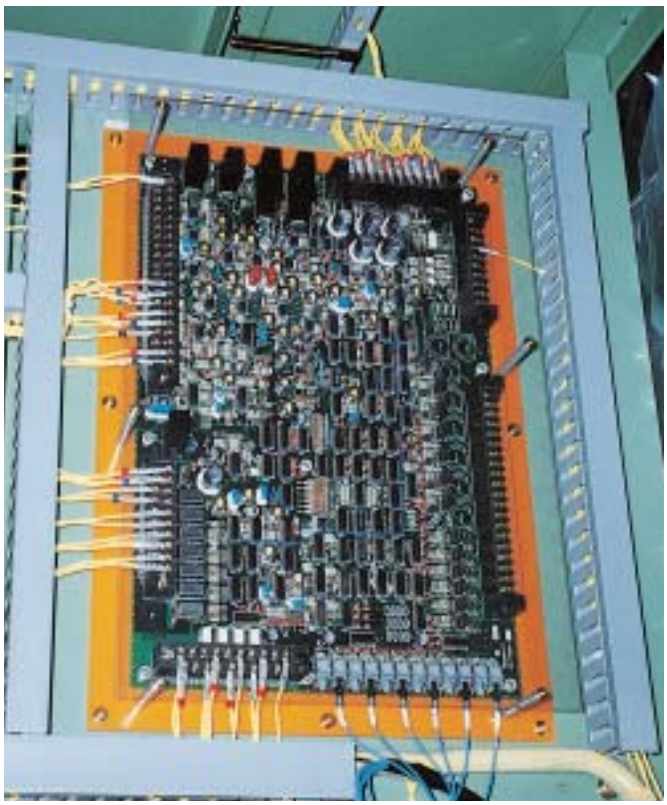
Rectifier systems for electrolytic services generally must be operated by an automatic current control system. For automatic output current control, a combination of voltage control functions as described on page 11 is utilized for diode rectifiers and whereas thyristor rectifiers, the output current is controlled by gate control of the thyristor.
Fig. 11 shows a typical automatic current control system for a diode rectifier system.
Fig. 12 shows a typical automatic current control system for a thyristor rectifier system.
Fuji Electric provides both an analog type controller and digital type controller for thyristor control. Customers can choose either one.

Fuji Electric offers a robust, stable and field-proven control device which can be easily linked to a computer and/or PLC (programmable logic controller) system.

Automatic current control unit for diode rectifier DK10968

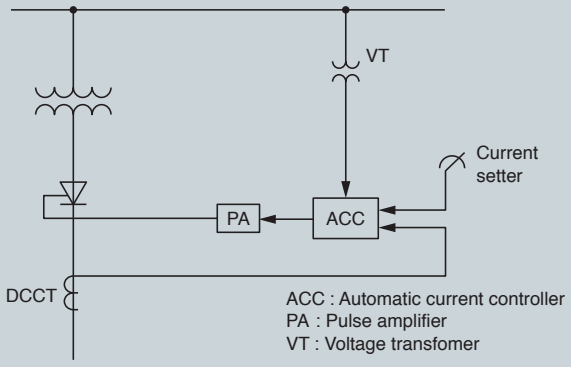
Fig. 11 Automatic current control system for diode S-Former





Automatic current control unit for thyristor rectifier DK10969

Fig. 12 Automatic current control system for thyristor S-Former



Control, protection and metering

Fuji is proud to offer user-friendly advanced SCADA (supervisory control and data acquisition) systems and associated HMI (human machine interface) systems for rectifier control. Our systems are designed based on our vast experience and actual operations in the field. A detailed brochure will gladly be provided upon request.

Fuji also takes pride in offering advanced protection and metering systems for rectifiers, which are supplied for electrolysis plant applications. Our continuous goal is always provide the very best solution for each individual user□s needs. By utilizing our extensive know-how in this field, we can provide our customers with the best design for their specific application.

Features

■ Using worldwide PLC/computer systems such as Rockwell (Allen Bradley), Modicon, Siemens

■ Operator friendly SCADA system

- **No operator training**
- **No operation manual**

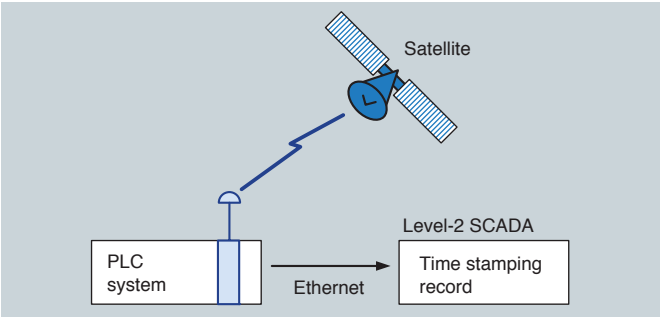
■ Easy overview

■ Easy modifications on hardware and software's

■ Backup HMI

- **Provided on Level-1 for PC system down (graphical operator interface system)**

■ High resolution record (time stamping system)

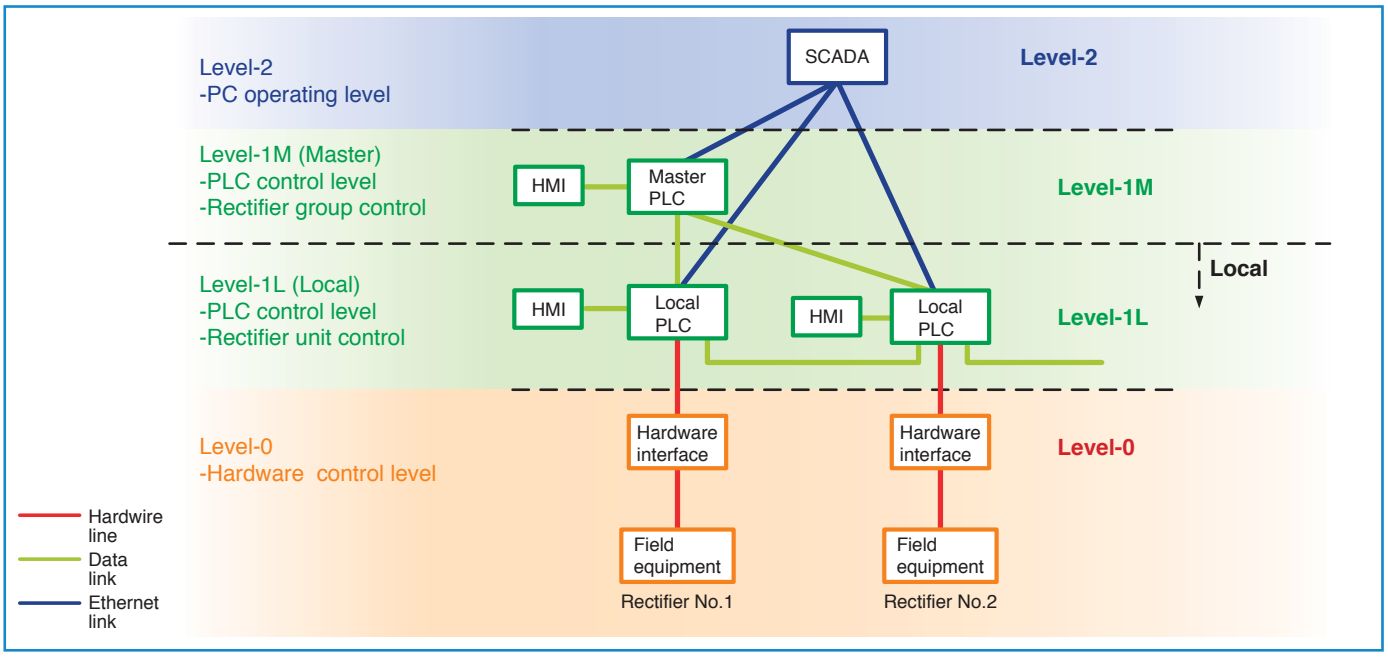


■ Easy status watching

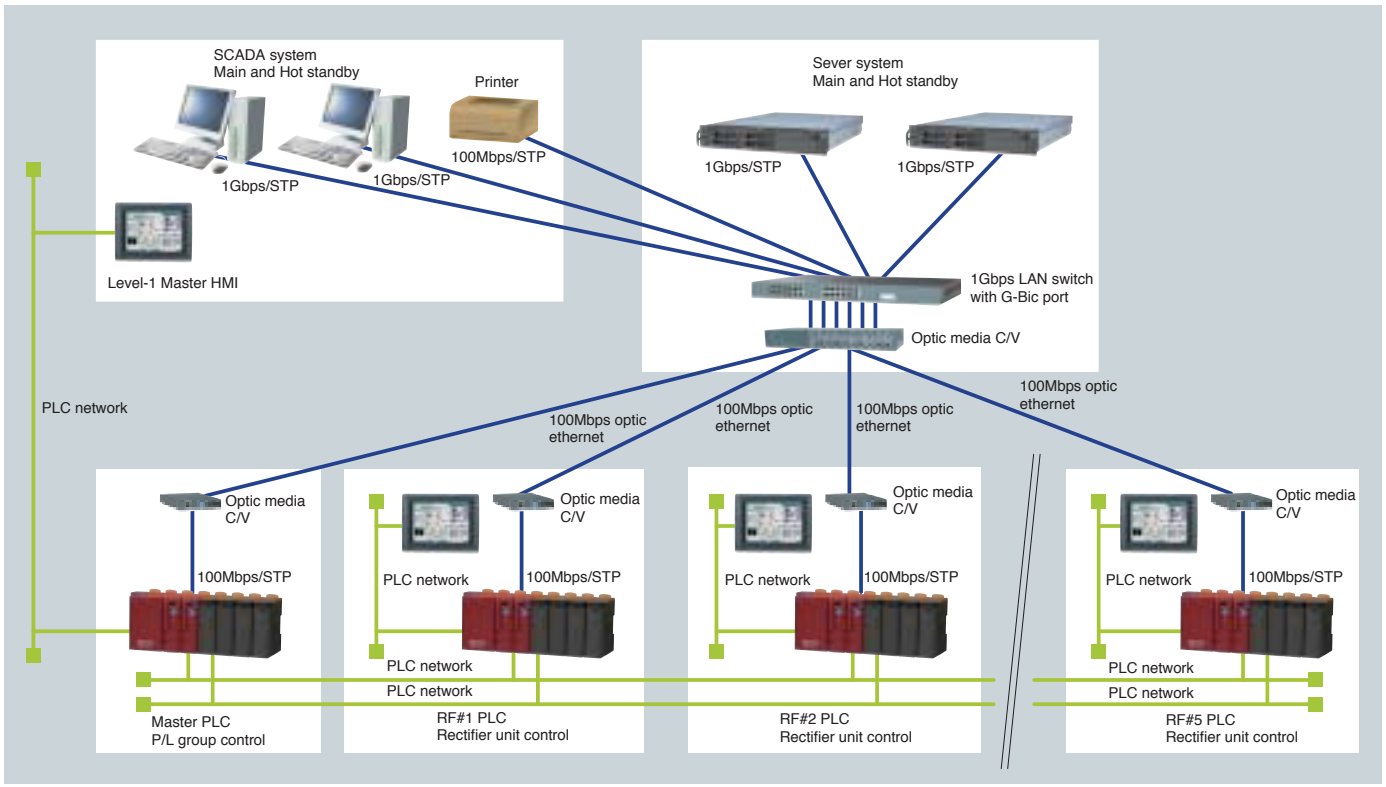
■ Human error protection

SCADA system

Standard control level configuration

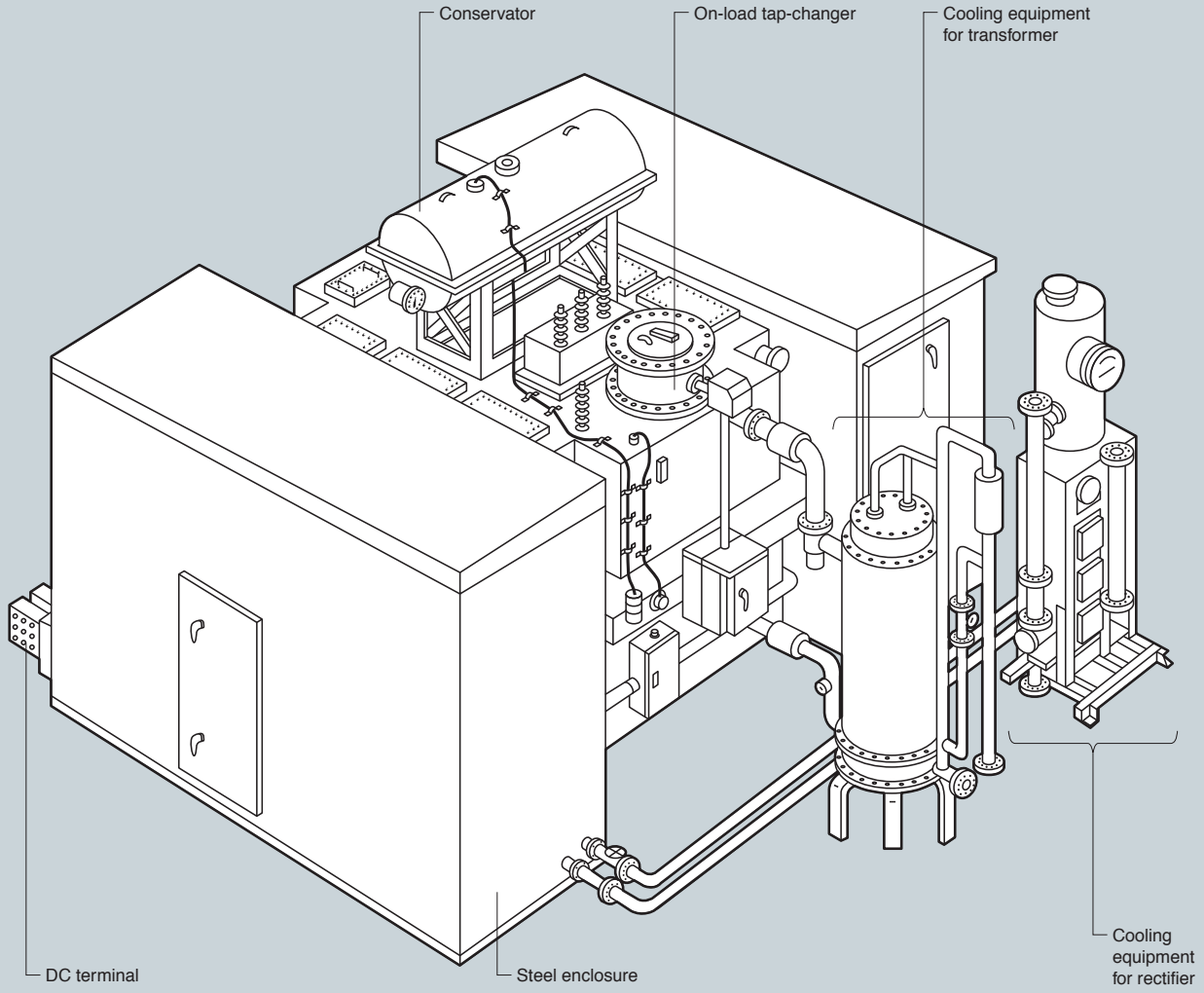


System configuration



Accessories

Fig. 13 Accessories



Note : Typical OFWF cooled transformer and WFWF cooled diode rectifier

Table 3 Transformer accessories

Description Standard Option	Standard	Option
Name (rating) plate	✓	
Cooling equipment	✓	
Conservator	✓	
Dehydrating breather	✓	
Bushings	✓	
Grounding pad	✓	
Terminal box for auxiliary circuits	✓	
On-load tap-changer		✓
No-voltage tap-changer		✓
Buchholtz relay with alarm and trip switches	✓	
Dial oil thermometer with an alarm switch	✓	
Dial oil level indicator with an alarm switch	✓	
Valves for oil drain, oil filling and oil sampling	✓	
Lifting lugs	✓	
Jacking bosses	✓	
Current transformer		✓
Oil purifier for on-load tap-changer		✓
Resistance temperature detector		✓
Ladder		✓
Wheels		✓
Winding temperature detector		✓

Table 4 Rectifier accessories

Description	Standard	Option
Protection fuses	✓	
Blown fuse indicator	✓	
Snubber with fuses	✓	
AC surge suppressor	✓	
Overheat detective device	✓	
DC output terminals	✓	
Steel enclosure, walk-in type	✓	
Interior lights with a switch	✓	
Terminal blocks for auxiliary circuits	✓	
DIW (*) water pump	✓	
Heat exchanger	✓	
DIW flow indicator with an alarm switch	✓	
Cooling water flow indicator with an alarm switch	✓	
Conductivity meter with an alarm switch	✓	
Dial DIW thermometer with an alarm switch	✓	
DIW water reservoir tank	✓	
Dial DIW level indicator with an alarm switch	✓	
Ion-exchanger	✓	
Cooling fan (**)	✓	
Door switch for alarm	✓	
Space (anti-condensation) heater	✓	
Lifting lugs	✓	
Reverse-current detector		✓
DC disconnect switches		✓
Resistance temperature detector		✓

Notes (*) DIW : De-ionized water (**) : In the case of WFAF cooled type

Transportation

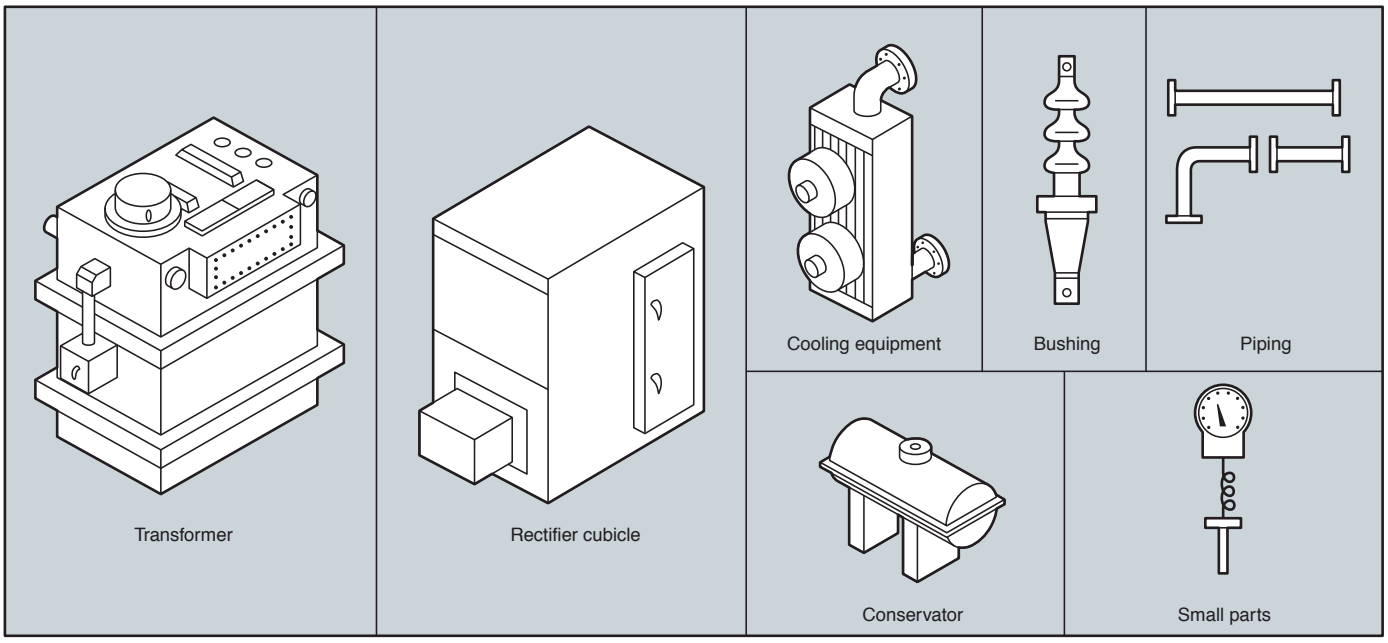
Fuji S-Formers are manufactured at our Substation Equipment Factory which has its own pier on Tokyo bay. Large S-Formers with export packing for ocean transportation are shipped to Tokyo or Yokohama port where they are loaded onto an ocean-going liner. Large S-Formers are disassembled into several parts as illustrated in Fig. 14.

Loading onto barge at Fuji Chiba Factory DK10970

Lifting from barge

Loading on ship

Fig. 14 Typical shipping with S-Former disassembled into several parts



Overview at site

Diode S-Formers for aluminum smelter, 132kV AC/1,450V DC, 82.5kA each

Diode S-Formers for aluminum smelter, 220kV AC/1,580V DC, 72kA each

Diode S-Formers for aluminum smelter, 132kV AC/1,330V DC, 85kA each

Thyristor S-Formers for chlor-alkali electrolysis, 33kV AC/520V DC, 4 × 30.3kA each

Printed on recycled paper

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