



# Rectifier

## Power Transformers for Industrial Applications

Industrial applications - such as the electrolysis process for aluminium or the chemical processes for zinc, copper and chlorine - require extra large volumes of high quality DC current. Coming from AC power, rectifier power transformers associated to rectifiers supply the required DC currents.

With over 35 years of experience supplying rectifier power transformers to more than 80 industrial projects around the world, GE offers reliable rectifier transformers adapted to your specific industrial processes and sites - whether for new plants or refurbishments. GE's power transformer experts work in close cooperation with rectifier suppliers to design the rectifier transformers and the electrical and mechanical interfaces to offer you the most optimised DC current solutions available.

### A Complete Range that fits Every Customer's Rectifier

Two ranges of Grid Solutions' rectifier power transformers answer the needs of all electrolysis processes:

- Mainly for zinc, copper, chlorine: 100-500 V DC, and up to 140 kA DC
- Mainly for aluminium: 240-1750 V DC, and up to 115 kA DC

Rectifier transformers are suitable for connections to all types and technologies of rectifiers:

- Bridge (Graëtz) or interphase (double - star), simple (6-pulse) or double (12- pulse), with diode or thyristor technology
- Regulating (auto) transformers associated with self-saturable reactors, or the rectifier thyristors, for fast tuning response needs for low voltage regulation of the industrial process
- Self-saturable reactors and inter-phase transformers are also part of our expertise and supply in rectifier transformer combinations, according to the technology and connection type of the rectifier.

GE's designs are based on decades of experience, expert calculations and CAD tools. The company offers rectifier power transformers that are precisely adapted to thermal, mechanical and dielectric constraints. GE's experts validate all design and production phases to ensure suitability to specific harmonics and very high currents in accordance with your project requirements.

Our special transformer designs take into account harmonic losses in accordance with IEC 61378 and ANSI standards. For applications with high DC currents and reduced harmonics on the voltage system, series transformers with defined phase shifts between units are supplied and connected to 12 to 96 pulse DC supply systems.

## Field of Expertise

- Electromagnetic compatibility
- Reliable thermal behaviour of connections
- Limitation and mastery of stray flux effects in active parts, surroundings and external equipment

## Key Benefits

- Tailor-made solutions
- Field-proven, high operational reliability
- Suitability to very high currents and harmonic levels
- Improved power quality
- Economical operation solution



## Mastering the Challenges

Combining the most innovative designs and the reliability of its field-proven technology, GE has mastered the challenges for global solutions that fit our customers' specific needs. With our broad technical expertise, we have optimised the design of power transformers and their interfaces with the rectifiers - for economical DC supply operations.



## Very High Current Levels

Electrolytic processes involve very high current levels up to a few hundred kA. For cost optimisation, the number of transformers connected in parallel to supply industrial processes tends to decrease, which therefore increases the current levels per transformer.

GE's know-how in power transformers for high current levels means that we have the mastery of associated leakage flux and induced phenomena:

- High circulating current in parallel coil connections
- Temperature rise due to eddy currents in large metallic surfaces and thicknesses in connections and structural parts.

Specific design rules, technologies and processes have been developed for critical parts such as:

- Seal off bushings for LV with high current rectifier connections
- Internal connections on the LV side.

## Oversized Transformers for Reduced Harmonics

Rectifiers based on diode or thyristor technology are the main sources of current harmonics (5-7, 11-13 and higher ranks).

Our power transformer technical designers work hand-in-hand with rectifier experts to define the harmonic spectrum and include it in the technical requirements specification.

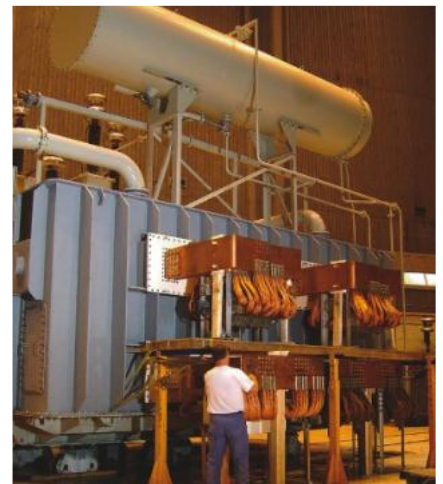
Transformer designs take into account the increase of losses due to distorted currents according to the specific harmonic spectrum. In order to decrease these losses:

- Windings are made of continuously transposed cable or thin flat conductors
- Busbar sections and geometry are optimised
- Aluminium or copper plates are used to protect the stainless steel tank wall on the LV side.

## Complex Phase-shifting Arrangements

For well balanced, quality power systems with an increased number of pulses, GE offers complex arrangement solutions with a large variety of phase shifting possibilities:

- For 12-pulse rectifiers, a 30° displacement between the two LV systems is obtained by star and delta winding connections on rectifier transformers
- The phase-shifting between rectifiers is made either by phase-shifting on the primary of the rectifier transformer via Zig Zag or extended Delta connections, or by phase-shifting on the regulating auto transformer. This innovative solution offers a simple and identical design for all rectifier transformers at the same plant.



## Connection Schematic Diagram

Interphase connection	> Secondary side	
	> Primary side	
Bridge connection	> Secondary side	
	> Primary side	

## Tailor-made Solutions

Rectifier transformer from GE combinations can be made in one single tank or two separate tanks. In the single tank solution, all active parts are grouped in one tank. This is an economical solution, offering a reduced footprint and reduced installation work.

In the two tank solution, the regulating (auto) transformer with its OLTC and/or OCTC is in one tank and the rectifier transformer assembly in the other.

## Regulation Solutions for each Specific Process Need

Electrolytic processes require wide regulation ranges and fast and tune voltage regulation.

- The wide regulation is carried out by a regulating (auto) transformer
- The fast and tune regulation is carried out either by a set of S.S.R. (self-saturable reactors) or by thyristors.

### Regulating (Auto) Transformer

Our regulating solution responds to the specific range of variation needed for industrial processes. Aluminium electrolysis rectifiers require a wide range of secondary voltage variation, up to 100%, to start the electrolysis pot line from the beginning. The whole range of regulation is split up into smaller ranges, either with a combination of OCTC + OLTC or with a multi-coarse OLTC. Copper, zinc, chlorine electrolysis rectifiers require a lower range of secondary voltage variations. The whole range may be achieved by either an off-circuit tapchanger on the rectifier transformer primary winding or by a regulating (auto) transformer using simple OLTC.

## Some Key References

Customer (site)	Country	Transformer rating
ALUAR Aluminium smelter	ARGENTINA	<b>Rectifier transformers 150 MVA, 132 kV / 2x1.330 kV - 80 kA DC:</b> auto-regulating (with phase shifting) and rectifier transformer in separate tank. Rectifier transformers (line in line) with saturable reactors
ASTURIANA DE ZINC (S. Juan Neiva) World largest zinc smelter	SPAIN	<b>Rectifier transformers 42.18 MVA, 132 kV / 4x0.490 kV - 122 kA DC:</b> auto-regulating, inter-phase reactor and rectifier transformer (double tier) in same tank, with phase shifting and saturable reactors
CORUS / RWE Aluminium smelter	GERMANY	<b>Rectifier transformers 67.125 MVA, 110 kV / 2x0.770 kV - 62 kA DC:</b> auto-regulating and rectifier transformer (line in line) in same tank, with phase shifting and saturable reactors
VINNOLIT Polyvinyl chloride (PVC) production	GERMANY	<b>Rectifier transformer 26.673 MVA, 110 kV / 4x0.377 kV - 100 kA DC:</b> auto-regulating and rectifier transformer (double tier) in the same tank, with saturable reactors and interphase reactors.
KHAS / RUSAL Aluminium smelter	RUSSIA	<b>Rectifier transformers 2 x 70 MVA, 107 kV / 2x1.285 kV - 80 kA DC:</b> rectifier transformers (line in line) with phase shifting and saturable reactors
PECHINEY (Vlissingen) Aluminium smelter	NETHERLANDS	<b>Rectifier transformers 89 MVA, 110 kV / 2x1.2 kV - 66 kA DC:</b> regulating and rectifier transformer in separate tank, with saturable reactors
HINDALCO Aluminium smelter	INDIA	<b>Rectifier transformers 188 MVA, 96 / 2x1.390 kV - 100 kA DC:</b> full-regulating and rectifier transformer (with phase shifting) in separate tank. The rectifier transformers (line in line) with saturable reactor
ALBA Aluminium smelter	BAHRAIN	<b>Rectifier transformers 48.7 MVA, 42.2 / 2x0.95 kV - 37 kA DC:</b> auto-regulating and rectifier transformer (with phase shifting) in the same tank. The rectifier transformers (line in line) with saturable reactors
ALCAN UPJ Aluminium smelter	CANADA	<b>Rectifier transformers 128.8 MVA, 71.4 / 2x1.004 kV - 95 kA DC:</b> auto-regulating and rectifier (with phase shifting) transformer in separate tank. The rectifier transformers (line in line) with saturable reactors

### Self-Saturable Reactors (SSR):

When connected to a diode technology rectifier, self-saturable reactors offer solutions for fast and tune voltage regulation. These SRR are placed in the rectifier transformer tank. Magnetic cores mounted on copper busbars carrying the main current produce a voltage drop. The saturation level of the magnetic core is controlled by a DC current circuit permitting a controlled variation of the voltage drop. This fine regulation range is equivalent to 2 or 3 steps of the OLTC. The SSR are critical components which require a specific know-how in electrical and mechanical design. GE's power transformer designers have this know-how and the company currently have several references of this type in successful operation.

### Inter-phase Reactors (or Inter-phase Transformers (IPT))

For rectifiers with inter-phase connections (copper, zinc or chlorine applications), an IPT has to be connected between the two neutral points of each double star LV winding. The DC middle point of the IPT is connected to the anode point of the DC load. The IPT permits the two elementary LV inter-phased 3-phase system supplied by a double star winding to work independently, so that each diode or thyristor can conduct during an angle of 120°.

The IPT can be housed either in the rectifier tank or in the regulating and rectifier transformer's common tank.

## Rectifier Power Transformer Range at a Glance

Industrial Process	Aluminium Process	Electrochemical Copper / Chlorine / Zinc process
Rated power MVA (fundamental)	40 to 212 MVA	10 to 60 MVA
Secondary voltage	240 V < U <sub>dc</sub> < 1750 V	100 V < U <sub>dc</sub> < 450 V
Current range I <sub>dc</sub>	37 kA < I <sub>dc</sub> < 115 kA	40 kA < I <sub>dc</sub> < 140 kA
Primary voltage	U <sub>p</sub> to (U <sub>m</sub> ) = 245 kV	U <sub>p</sub> to (U <sub>m</sub> ) = 150 kV
Rectifier connection type	Bridge (Graëtz)	Inter-phase (Star-Star, Double star-star)
Rectifier transformer connection	Y(y0) ± α D (y11) ± α or Y(d11) ± α D (d0) ± α or Y(y0 d11) ± α or D (d0 y11) ± α	Y(y0y6) ± α or D(y11y5) ± α
Regulation and tapping	OLTC and OCTC 0 to 100 % voltage regulation range	OLTC and OCTC 0 to 100 % voltage regulation range
Intermediary voltage (regulating (auto)-transformer secondary side)	Range 1: 36 kV Range 2: 72.5 kV Range 3: 100 kV Range 4: 123 kV Choice of tapchanger	Range 1: 36 kV Range 2: 72.5 kV Choice of tapchanger
Combined impedance Regulation + Rectifier	10 % to 16%	6 % to 14%
SSR (*)	YES /NO	YES /NO
Interphase reactors	NO	YES
Rectifier number (**)	From 4 ( 3+1 ) to 8 ( 7+ 1 ) rectifiers	1 or 2
Pulse	12 x number of rectifiers	6 , 12 , 24
Mechanical design	One or two tank design	One or two tank design
Oil-immersed transformers	With conservator	With conservator
Type of cooling	Regulating auto transformers only: Regulating (auto) transformers and rectifier transformers:	ONAN, ONAF, OFAF, ODAF OF AF, OFWF, ODAF
Ability to withstand short-circuits	The transformers are designed to withstand the thermal and the dynamic effects resulting from a secondary short-circuit in accordance with IEC 60076-5	
HV and LV terminals	HV: in air bushings, cable boxes or SF <sub>6</sub> connections LV: seal off bushings	
Equipment	> Standard and special equipment according to customer needs and specifications > Monitoring equipment: Grid Solutions' MS3000 range, on request. For on-line assesment of: <ul style="list-style-type: none"> <li>- aging rate</li> <li>- overload capacity</li> <li>- cooling efficiency and running time</li> <li>- tapchanger mechanical quality</li> <li>- required maintenance</li> </ul>	

(\*) SSR : Self Saturable Reactor

(\*\*) Rectifier : Rectifier transformer + rectifier

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