



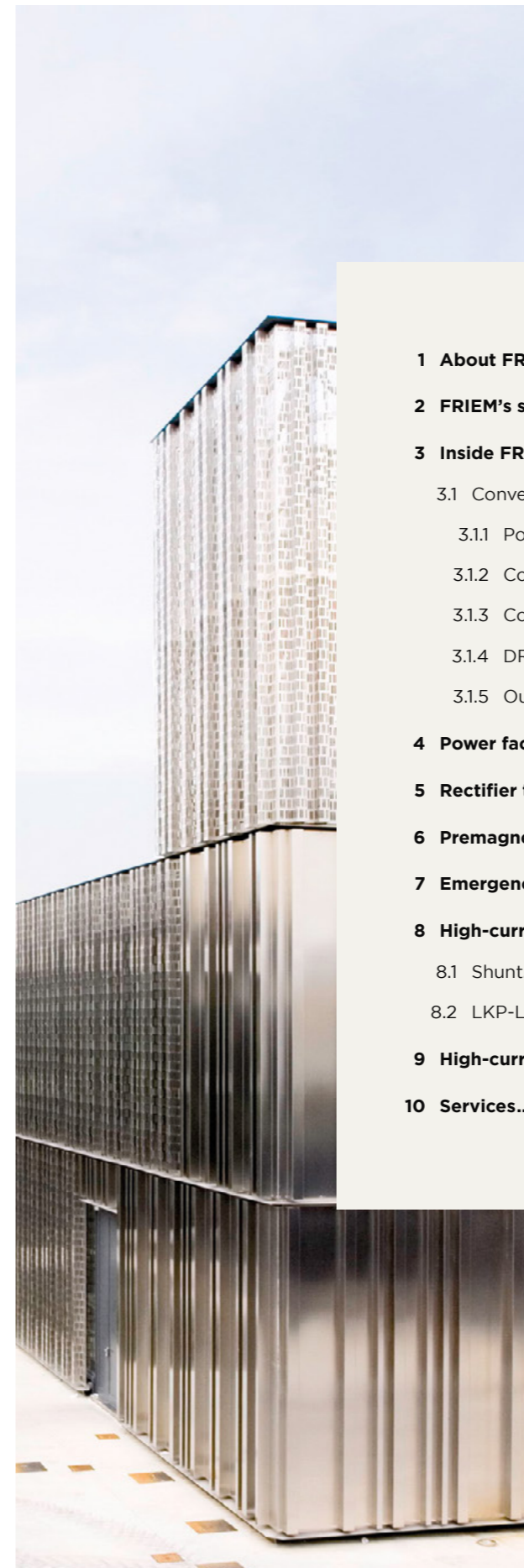
# **High-power converters**

## **Rectifier systems for industrial applications**



# Table of contents

<b>1 About FRIEM</b> .....	1
<b>2 FRIEM's solution</b> .....	2
<b>3 Inside FRIEM's conversion system</b> .....	3
3.1 Conversion system .....	4
3.1.1 Power section .....	6
3.1.2 Cooling section.....	6
3.1.3 Control section .....	7
3.1.4 DRP 7.0 .....	8
3.1.5 Outdoor containerised rectifiers .....	9
<b>4 Power factor compensation &amp; harmonic filter system</b> .....	10
<b>5 Rectifier transformer</b> .....	11
<b>6 Premagnetisation unit</b> .....	12
<b>7 Emergency and polarisation rectifier</b> .....	13
<b>8 High-current measurement system</b> .....	14
8.1 Shunt.....	14
8.2 LKP-LKAT-LKCO.....	14
<b>9 High-current disconnect switches</b> .....	15
<b>10 Services</b> .....	16



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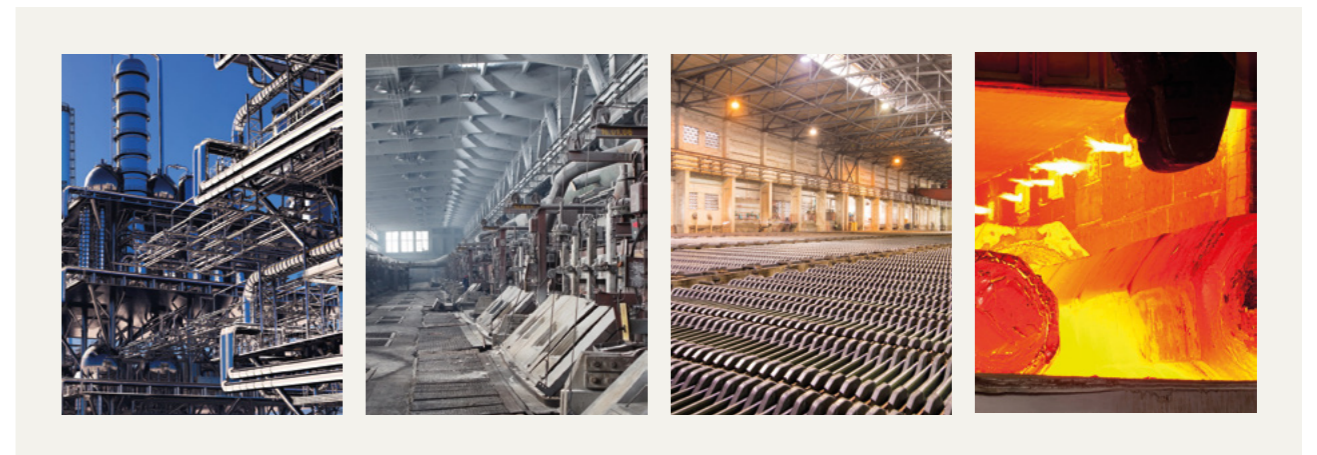
# About FRIEM

EXPERT IN ENERGY CONVERSION SINCE 1950

FRIEM is a global leader in electric energy conversion. As one of the top international players in the high-power rectifier industry with over 70 years of experience, FRIEM supports the primary industry with expertise and accountability.

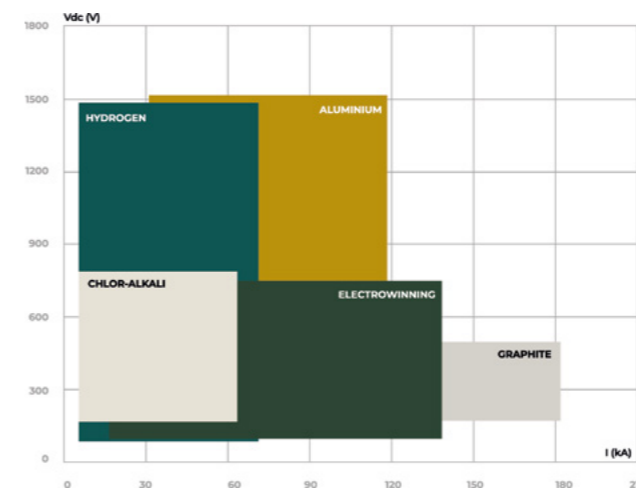
## Reliability and efficiency

FRIEM's rectifier systems are characterised by exceptional reliability and efficiency. Specifically developed for the heavy industry and particularly for processes where high direct current is required, FRIEM's equipment is custom-designed and tailor-made in accordance with the highest quality standards.



## FRIEM's rectifier systems meet the most demanding plant requirements.

Rectifiers ratings per application



CHLOR-ALKALI	Rectifier systems for electrochemical processes such as chlor-alkali and its derivatives; used for medical applications and by construction as well as pulp and paper industries
ALUMINIUM	Rectifier systems for the production of primary aluminium from alumina
ELECTROWINNING AND ELECTROREFINING	Rectifier systems for the extraction of copper, zinc, and other non-ferrous metals
GRAPHITE	Rectifier systems for the graphitisation process
HYDROGEN	Power supply units (PSU) for green hydrogen electrolysis production

# FRIEM's solution

FRIEM provides the rectifier and all the equipment needed for the conversion system.

Our rectifier systems are designed to meet the plant's most specific requirements and work in the most challenging operating conditions while maintaining high efficiency over the years. The design is optimised both for diode and thyristor rectifiers.

The digital current regulator DRP 7.0, designed and manufactured entirely by FRIEM, grants the highest reliability, safety, and overall performances.

Additionally, after the delivery, FRIEM provides lifetime support through its service assistance.



**Customised solutions**



**Flexible and modular design**



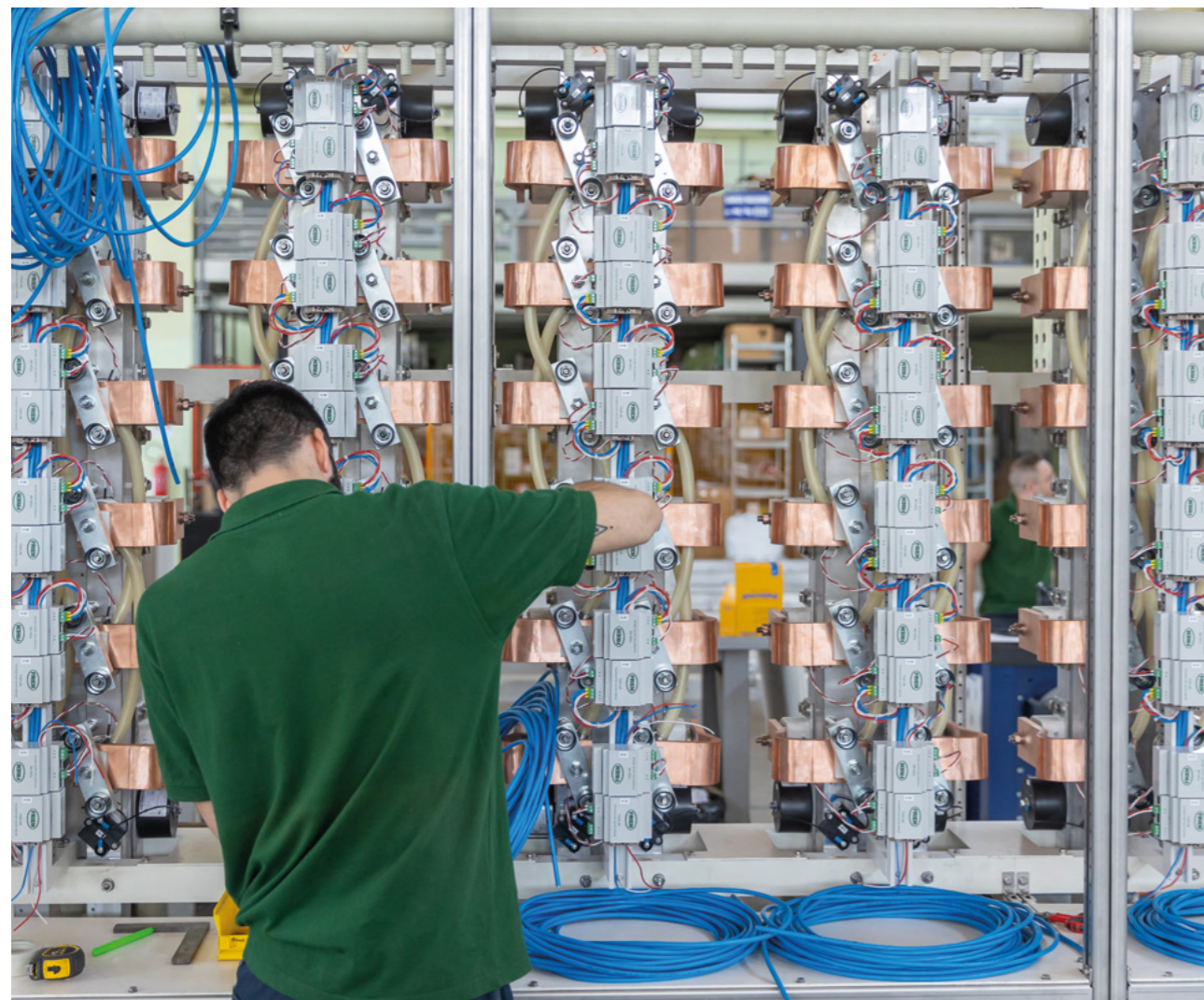
**High efficiency**



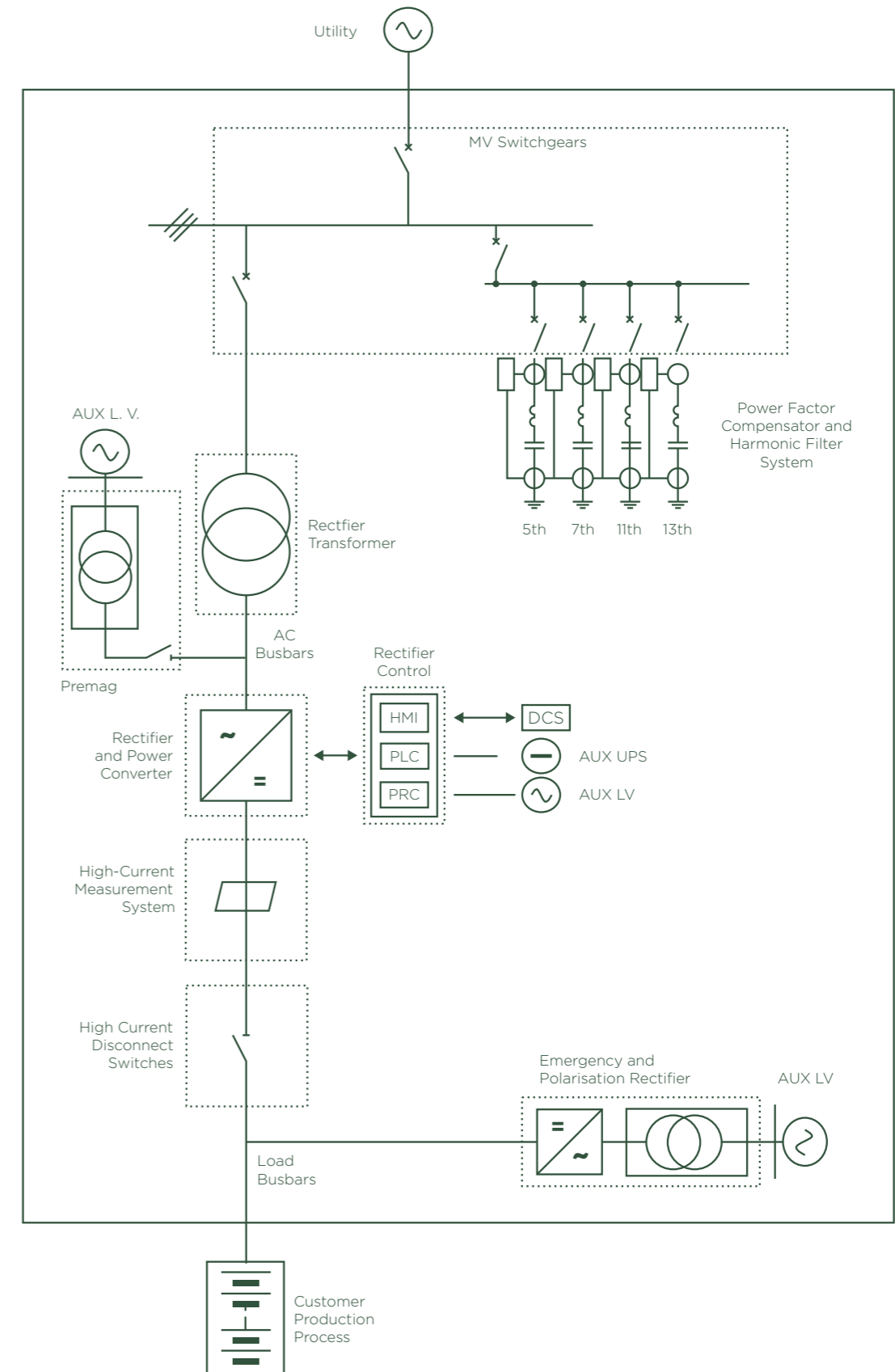
**Containerised solution available**



**Support throughout the plant's lifetime**



# Inside FRIEM's conversion system






# 3.1 Conversion system

The rectifier cubicle is a free-standing cabinet enclosed in a non-magnetic material.

Composed of a **power section**, a **control section**, and a **cooling section**, the rectifier unit can be installed either indoors and outdoors according to plant specifications.

The general assembly of the rectifier can be customised according to customer's requirements. For example, AC and DC connections, as well as cooling water connections, can be provided from the top or bottom of the cubicle.

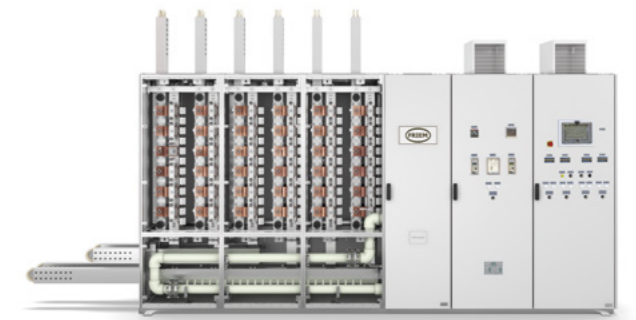
## SOLUTION AVAILABLE

-  **Air**
-  **Water**
-  **Deionized water**



## TECHNICAL DATA

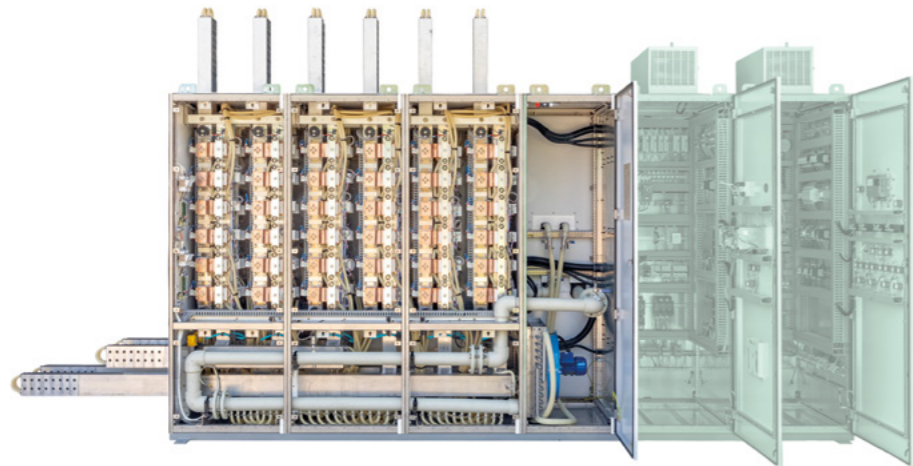
Connection	Full-wave bridge Full-wave double-bridge (series or parallel) Half-wave double-star - 2x double star Active front-end rectifiers
Type	Diode   Thyristor   IGBT
DC output current	Up to 180 kA per rectifier cubicle
DC output voltage	Rectifier: up to 1.500 V DC/DC converter: up to 3.000 V Up to 150.000 V for special applications
Control	0.1% standard accuracy digital current
Regulation	Current   Voltage   Power
Installation	Indoor   Outdoor (container)
Standards	IEC/ANSI/IEEE



### 3.1.1 Power section

#### MAIN FEATURES

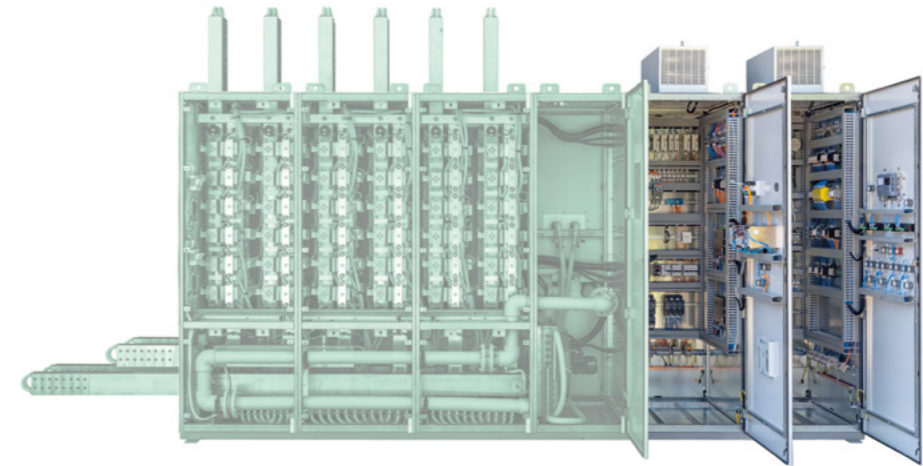
- Unique aluminium extruded busbars
- High efficiency and ability to withstand dynamic stress
- High reliability and long operational life due to reduced operating temperatures
- Optimised number of semiconductors and n+1 valves redundancy as standard
- Non-magnetic material rectifier cubicle
- Simplified design of a transformer's phase connections
- Optimised design for thyristors balancing
- Easy maintenance



### 3.1.3 Control section

#### MAIN FEATURES

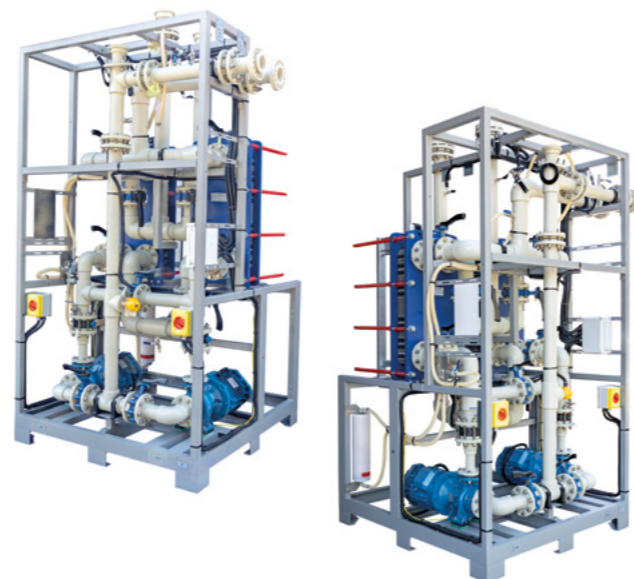
- Digital current regulator (FRIEM DRP 7.0) for diodes, thyristor, and IGBT
- PLC and HMI control and automation (different brands available)
- Hot and warm PLC redundancy
- Fiber-optic thyristor firing and connection with the remote control section
- Redundant Direct Current measurement
- Local, remote, and master control
- Remote control via Profinet, Profibus, or Ethernet



### 3.1.2 Cooling section

#### MAIN FEATURES

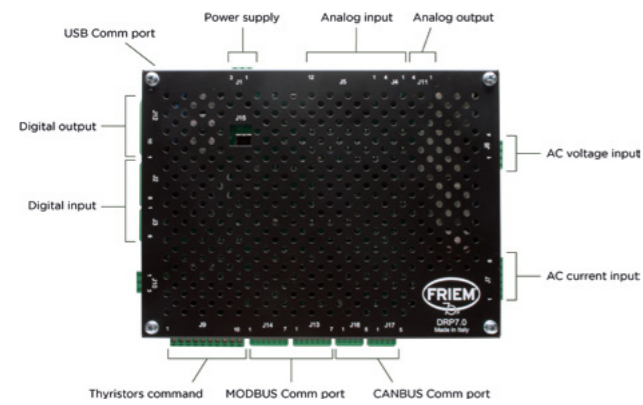
- Deionised water to raw water cooling system (dWFWF)
- The types of cooling available:
  - Deionised water to raw water
  - Deionised water to air
  - Air-forced
- Pressure sensor, flow meter and temperature monitoring for deionised and raw water. Deionised water level sensor (low and high)
- High availability to include redundancy for the main components (i.e., pumps, heat exchangers and IP54)
- Open (IP00) or enclosed section (IP 54)
- Easy maintenance



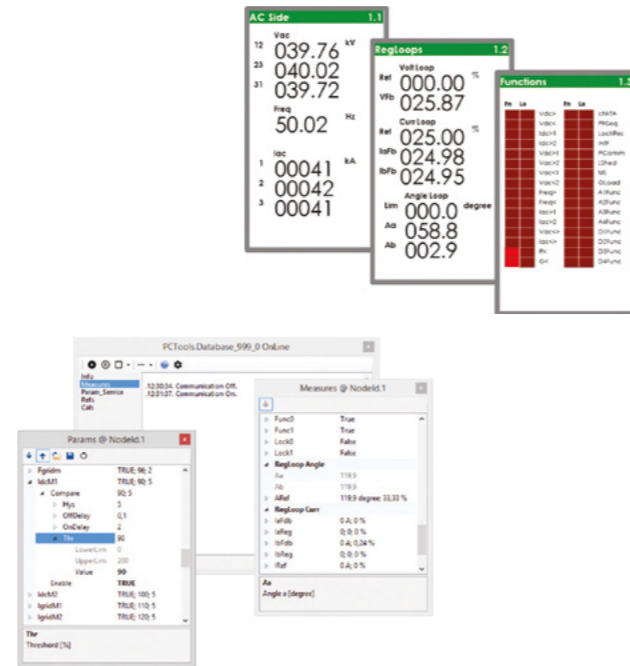
### 3.1.4 **DRP 7.0**

DRP 7.0 is the latest generation of FRIEM's current-voltage digital regulators. DRP 7.0's new dedicated functions support the degraded conditions of the rectifier (i.e., lack of feedback or reference signals), by instantaneously swapping between failed and valid signals.

By using a dedicated software tool (i.e., Microsoft Windows), it is possible to check the electrical measurements, update parameters, download events and trends, and quickly reconfigure a new regulator thereby, minimising the plant's shutdown time.



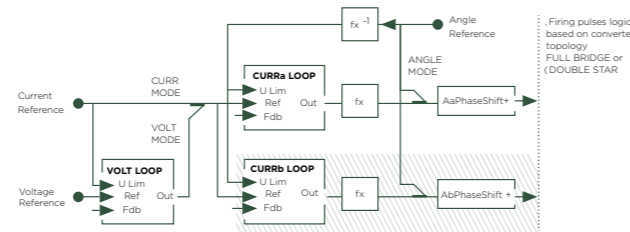
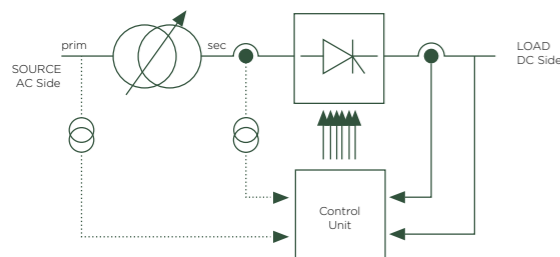
An optional Human Machine Interface (HMI) adds supplementary features such as checking and setting measures, ensuring remote management via Internet for troubleshooting, and performing maintenance as well as firmware upgrade activities.



#### GENERAL FEATURES

- Full closed-loop digital regulator for bridge or double-star thyristor-based converter topologies, with three selectable regulation modes: DC current setpoint with voltage and/or angle limitation, DC voltage setpoint with current and/or angle limitation, and firing angle setpoint
- Independent control of each phase with response time that is one-sixth of the period ( $T = 50-60 \text{ Hz}$ )
- Dual independent closed-loop current regulators for managing double-star converter topologies with a single control board
- Regulator accuracy = **0.1% full-scale value**
- Starting regulation setpoint  $\leq 0.2\%$  full scale value
- Quick installation and configuration through dedicated software (Microsoft Windows)
- Specific functions for quickly detecting of feedback signal anomalies and automatically swapping to a backup sensor
- Specific functions for quick current setpoint reduction (LOAD SHED), with a reaction time of  $< 50 \text{ ms}$
- Diagnostic functions such as event and trend recording, which are stored in flash memory
- Configurable protection functions such as mains voltage and current, frequency, voltage and current output, unbalance of mains voltage and current, phase sequence, load impedance,  $I^2t$
- Configurable sequences such as instantaneous shutdown, current fade-off ramp, and angle fade-off ramp

More info available in the DRP7.0 catalogue



### 3.1.5 **Outdoor containerised rectifiers**

The rectifier system can be containerised if outdoor installation is needed. FRIEM's solution provides utmost reliability, availability, and efficiency, especially in harsh climatic conditions.

#### PRODUCT FEATURES

- Made of metal, and non-magnetic metal, or non-metallic material, and suitable for harsh, industrial environment
- Includes a temperature with two stages, lighting facilities, a cooling system, and doors with a safety bar
- Protection degree: IP65
- A walk-in type container with doors that provide enough space to perform the required rectifier maintenance activities inside
- Redundant air-conditioning or air-to-water system



## Power factor compensation & harmonic filter system

FRIEM provides power factor compensation and harmonic filter systems dedicated to plants with power converters.

Each system consists of a three-phase capacitor bank connected in series with three single-phase filter reactors connected to the MV line in order to tune the relevant series resonance frequency of the circuit.

### TECHNICAL FEATURES

- Tuning frequency: 5-13 kHz
- Latest IEC, ANSI/IEEE, and IS Standards
- Air-insulated reactors designed for outdoor/indoor installation
- Oil-insulated capacitors designed for outdoor/indoor installation
- Support frames made of hot-dipped galvanised steel
- Connection bars made of copper conductors
- Vertical or horizontal installation
- Metal-enclosed solution for outdoor/indoor installation

### ACCESSORIES AND OPTIONS

- Current unbalance protection
- Overcurrent protection
- Three-phase multifunction microprocessor protection relay
- Optimised management of the system made by the rectifier control panel
- Disconnect switches for maintenance purpose
- Surge arresters

## Rectifier transformer



The rectifier transformer is fully integrated in the system through a detailed technical specification. It optimises the connection to the rectifier.

### SOLUTION AVAILABLE

Liquid-oil filled or dry-type cast resin

### PRODUCT FEATURES

#### High performance

- Designed to work with all temperatures (-50 °C to +55 °C) and altitude (>4000 m asl)
- Specially designed for rough environment (corrosive atmospheres, seismic zones or hazardous areas)
- All cooling system types are available by means of mineral oil or less-flammable fluids, air or water external cooling mediums and natural or forced circulation
- Equipped with NLTC or OCTC to allow voltage regulation

### TECHNICAL DATA

Connection	Bridge/double-bridge or double-star (with IPT)
Pulse number/unit	6, 12, 18, 24, and more
Type	Liquid oil-filled or dry-type cast-resin
Capacity	Up to 200 MVA
Primary voltage	Up to 220 kV
Cooling system	ON-OFF/AN-AF-WF
Options	Regulating autotransformer and saturable reactors available in the same tank to allow no-load fine voltage regulation
Standard	IEC, IEEE/ANSI





## Premagnetisation unit

During the uncontrolled energisation of the transformer, the large transient current can reduce the transformer's lifespan due to flux saturation in the core (i.e., inrush current) and the high mechanical stresses involved. Moreover, this can lead to unexpected operation of protective relays and power quality-reduction. If this occurs, the transformer and protective systems must be checked to define the faults. The inrush current can cause serious electromagnetic stress impact and shorten the lifespan of the transformer. Further, the over-voltage resulting from this event may cause damages to other power devices and voltage drop in the feeding network.

### PRODUCT FEATURES

- Operates with transformer connected to HV or MV networks and at 50 Hz or 60 Hz
- Can operate with OLTC-equipped transformers as well with OCTC-equipped transformers
- Suitable for vacuum or gas circuit breaker
- The premagnetising cycle is managed by the PLC automatically at the act of commanding the closure of the MV circuit breaker (operation of the OPEN/CLOSE key on the rectifier control panel)
- If needed, the premagnetisation intervention can be inhibited, by using a dedicated function on the HMI



FRIEM's premagnetisation unit provides a solution to limit the inrush current during the start-up of the main rectifier transformer, which involved premagnetising the transformer core from an independent source and limiting the voltage variation at the insertion, thereby containing the inrush current.

FRIEM's premagnetisation unit has a specific design for each transformer or set of transformers.

## Emergency and polarisation rectifier

The emergency and polarisation rectifiers are designed to operate in the 'constant current' or 'constant voltage' modes.

They give a constant DC output to the electrolyser cells during the shutdown of the main rectifier, with a maximum current clamping regardless of the output voltage.

The emergency and polarisation rectifier is continuously connected to the cells and operates on stand-by mode.

Thanks to its ability to communicate with the main rectifier control panel, the system grants maximum performance in terms of time response, safety, availability, and reliability.

### TECHNICAL DATA

Connection	Full-wave bridge (series or parallel) Full-wave double-bridge (series or parallel)
Type	Diode   Thyristor   IGBT
DC output current	50 A to 3 kA
DC output voltage	Up to 1.500 V
Cooling	Air   Water   Deionized water
Control	0.5% standard accuracy digital current
Regulation	Current   Voltage   Power
Operating mode	Stand-by   On-line
Installation	Indoor   Outdoor (container)

### PRODUCT FEATURES

- Designed in accordance with the latest IEC and ANSI/IEEE Standards
- Power supply: low voltage, three-phase
- Semiconductor: thyristor, diode, or IGBT
- Protection degree: IP20 to IP54
- Cooling system: air-forced
- Air conditioner as optional
- Dry-type reactor on the DC side as standard
- Digital current and voltage control as standard
- PLC and HMI as standard

FRIEM's emergency and polarisation rectifier consists of:

- a dry-type transformer
- a thyristor rectifier
- control and auxiliaries sections

The equipment includes all the devices required for synchronisation, control, signaling, alarm, and protection to ensure a satisfactory operation of the unit.

Thanks to FRIEM's design and flexibility, the emergency and polarisation rectifier can be customised to meet and satisfy the different requirements of our customers.



## High-current measurement system

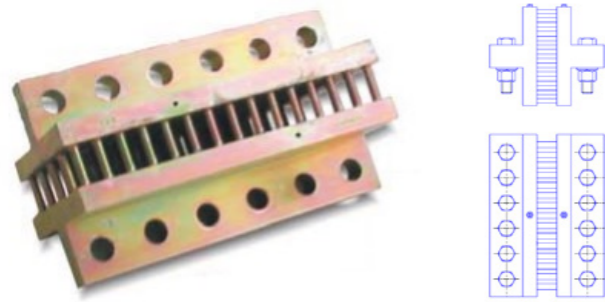
High-current measurement systems are used to measure and monitor high Direct Current. Typically each system is made by a sensor, which is placed in the path of the current flow, and a measurement board, which is used

to read and analyse the output. The sensor technology depends on the application and the level of accuracy required. You can find what we are offering below.

### 8.1 Shunt

A shunt is a low-value resistor that is series-connected to the DC output of the rectifier. It is properly designed for the rated DC current.

By measuring the small voltage drop generated across its terminals, it is possible to determine the value of the current flowing through it, with negligible effects on the measured value.



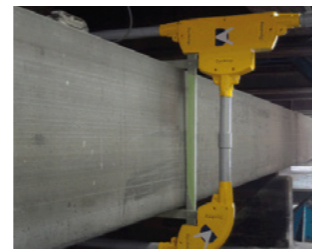
#### TYPICAL DATA

Accuracy	0.5%
Standard voltage drop	60 mV
Temperature coefficient	0.002 % / °C
Rod material	Manganin
Continuous overload current	1.2 In
Max overload current (for 5 sec.)	2 In
Operating temperature	- 25 / + 60 °C

### 8.2 LKP-LKAT-LKCO

Thanks to DynAmp, a company of the FRIEM group, FRIEM offers a number of measurement technologies to fit the specific needs of each application:

- Fully compensated optical technology
- Closed-loop hall effect technology
- Advanced OLOP technology
- Rogowski coil technology



#### MAIN FEATURES

- High accuracy current measurement from 0.5% FS to 0,1% of reading to over 600 kA
- Uni-directional and bi-directional current measurement system
- Multifunction rectifier protection system
- Rectifier condition analysis system
- Cell voltage monitoring system for membrane chlorine processes
- Anode monitoring and control system for mercury cell chlorine processes
- Portable clamp-on high-current measurement instrumentation

## High-current disconnect switches

FRIEM takes care of the engineering needed for the installation of the switches in the bus ducts. Isolating/disconnect switches can be installed in any position and directly into the busbar system.

Switches are available to be connected to either to copper or to aluminium busbars or through bolting or welding. To avoid additional stress on the busbars caused by the disconnectors' weight, FRIEM designs dedicated supports for the switches.

Although disconnect switches are self-supporting, busbar supports must be designed to withstand the switch's additional weight. The disconnect switches can be operated at no load or on load.

The isolating/disconnect switches can either use:

- sealed contact assembly to increase safety and withstand chemical environment

- mechanically independent mobile contact arms provided with high-pressure springs.

Moreover, electrical contacts are provided with silver-to-silver contact.

The isolating/disconnect switches can be customised with:

- input and output terminals in aluminium or silver-plated copper (two-poles)
- different controls available: manual, pneumatic or motorised.

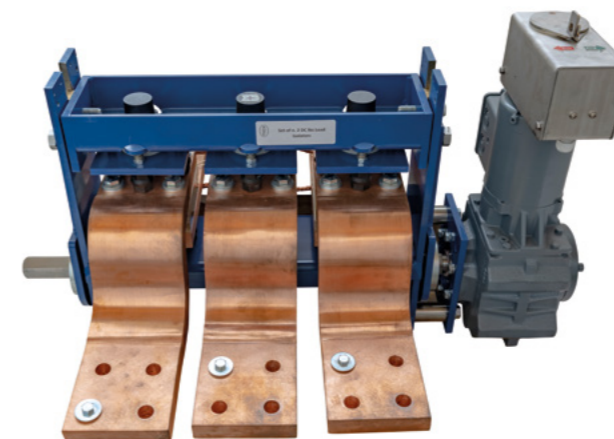
All our high-current disconnect switch manufacturing activities meet the ISO 9001 standards.

#### TECHNICAL FEATURES

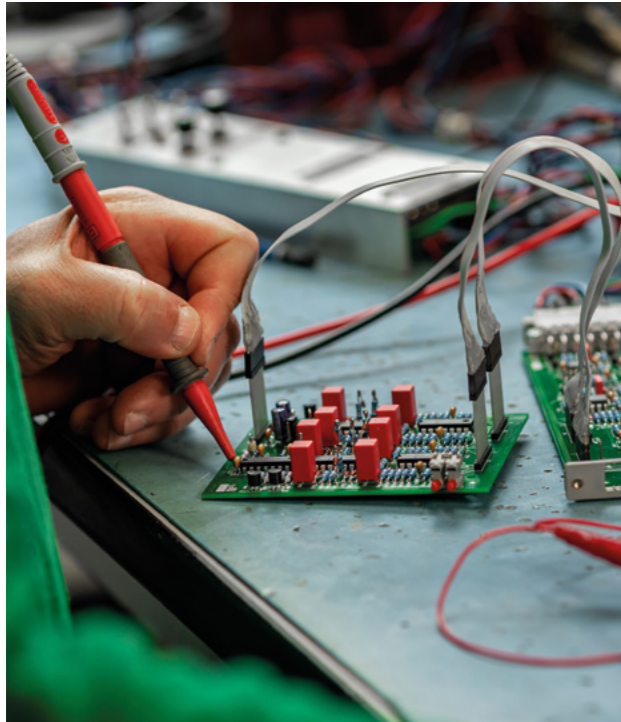
- Rated current: up to 72 kA
- Very low contact resistance
- Low voltage drop
- Low contact heating
- Low maintenance
- High electrical and mechanical durability
- Easy connection to:
  - Aluminium busbar by welding
  - Copper busbar by bolting
- Wide modular range
- Load break option of up to 1,200 Vdc
- Large-scale customisation possible with:
  - actuators (motor, pneumatic, manual)
  - accessories (limit switches, locks, temperature sensors)
- Safe operation

#### APPLICATIONS

- Output rectifier isolation
- Cells isolation for electrolytic process






FRIEM provides a vast range of services to fit each customer's need. Our services, which are completely customisable, help in reducing the lifetime costs of equipment and plants, along with increasing their performance and efficiency, as well as the entire rectifier's lifespan.



#### ONSITE TECHNICAL SUPPORT

##### WHEREVER YOU ARE, WE ARE




Along with you, we plan the right onsite support you need after the equipment is delivered, and, in case of an emergency, we can reach you immediately thanks to our extensive network of local service partners.

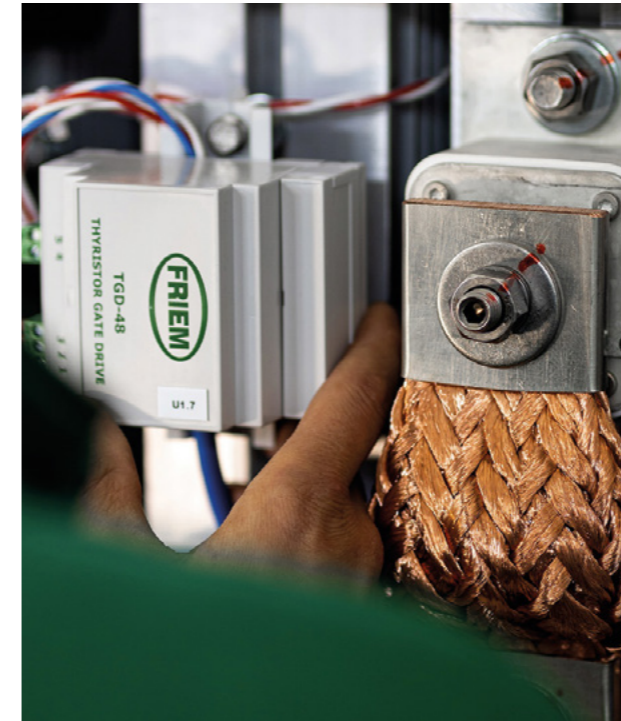
-  **Installation supervision**
-  **Commissioning & start up**
-  **Maintenance**

#### REMOTE ASSISTANCE

##### A DIRECT LINK TO FRIEM'S HEADQUARTERS

We at FRIEM provide remote support that guarantees quick responses in all situations. Our remote service can be an emergency solution or an alternative to the onsite

-  **On-call service**
-  **Augmented reality remote assistance**
-  **Standard remote service (FIRS)**






#### UPGRADE AND TRAINING

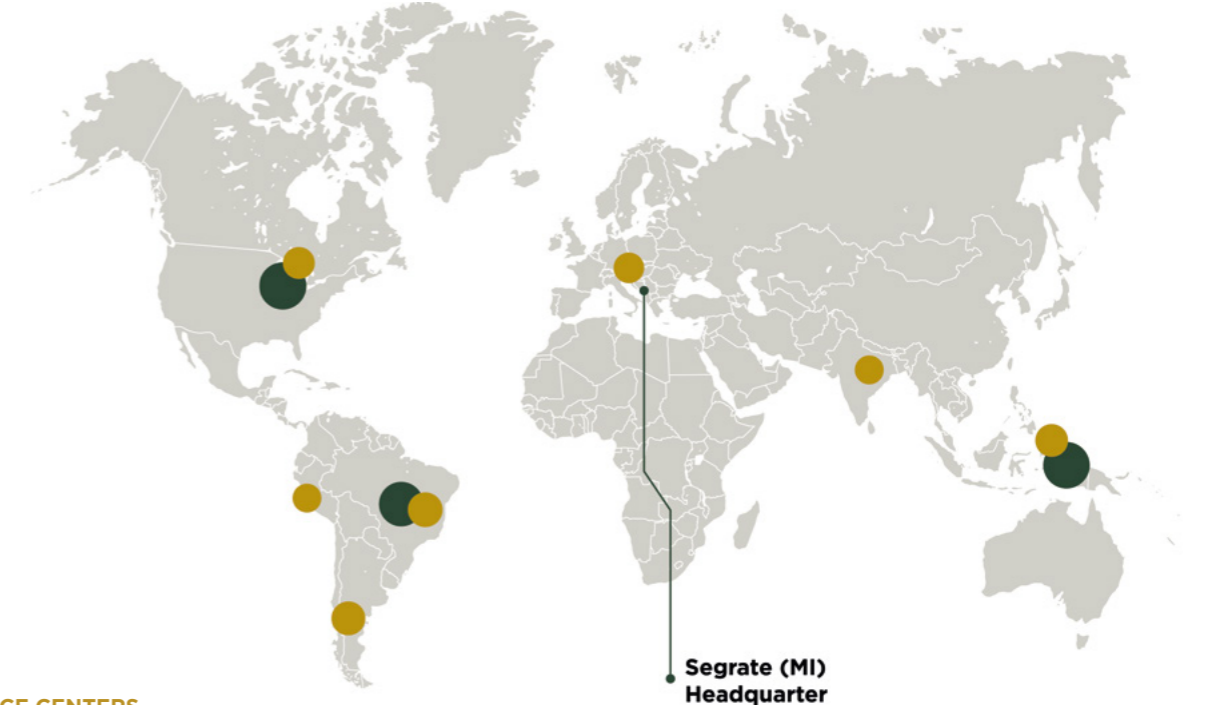
##### SHARING EXPERIENCE AND KNOWLEDGE

Through bespoke training, we at FRIEM provide you with all the information you need to preserve the equipment properly, operate at maximum performance, and prevent failures.

To minimise the risk of shutdown due to the obsolescence of the equipment, our experts can suggest the best technical solution for you to improve your system using new technologies.

-  **Revamping and upgrade**
-  **Conversion system efficiency assessment**
-  **Training**

#### WORLDWIDE PRESENCE



##### 7# SERVICE CENTERS

FRIEM (Milan, Italy)  
 FRIEM America (Chicago, US)  
 FRIEM LATAM (San Paolo, Brazil)  
 FRIEM Asia (Jakarta, Indonesia)  
 FRIEM India (New Delhi, India)  
 FRIEM Perù (Lima, Perù)  
 FRIEM Chile (Santiago, Chile)

##### 3# SERVICE SUBSIDIARIES

FRIEM America, Chicago, US  
 FRIEM Latam San Paolo, Brazil  
 FRIEM Asia, Jakarta, Indonesia



## FRIEM S.p.A

FRIEM is an Italian technology manufacturer founded in 1950, which specialises in the design and production of electrical converters for special applications. As one of the top four global players in the high-power rectifier industry, FRIEM has reached a turnover of approximately 35 million euros (out of which, over 90% of the amount stems from abroad), 1.5 GW of production capacity, while employing over 100 people worldwide.

FRIEM, being a European leader in the green hydrogen production using electrolysis for large power plants, supports the energy transition by assuming a central position in the value chain.

The group consists of the parent company FRIEM S.p.A., with its headquarters in Segrate (Milan); two subsidiaries based in the United States (FRIEM America Ltd); in Brazil (FRIEM LATAM Eireli), a commercial office in Indonesia; and DynAmp, an American producer of high-DC current measurement systems. Through EYES, an Italian start-up, FRIEM serves the electrical mobility market, and with the support of the Italian TCE Consultore, it provides power electronics consultancy. In April 2022, Fondo Italiano d'Investimento, entered FRIEM's capital through FITEC, with a minority share to accelerate growth and investments.



CONVERTING TECHNOLOGY

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