Powering Progress with FRIEM's rectifiers

Continuous Improvement in Chlor-Alkali Power Conversion

Maurizio Stucchi

Head of Industry

FRIEM S.p.A.

12th International Chlor-Alkali Technology Conference & Exhibition

13-15 May 2025
Barcelona - Spain

About FRIEM

A global player in **high-power rectifiers** for the electrolysis, metal refining, graphitization and aluminum industries.




Main figures

2024

Foundation
1950

Capacity **GW 1,5*** (Segrate)

Turnover
mln € 54**

Employees
160

Order Intake
CAGR ‘20 – ‘23
+20%

R&D
expenses/turnover
>5%

- *Production Capacity expansion to 2 GW @ 2025 end*
- *** Group aggregate 2024*

The Mission of FRIEM

Empower successful chlor-alkali production with innovative, reliable, and efficient customized **rectifier systems**, backed by continuous support, building lasting and valuable partnerships.

FRIEM Group

Fondo Italiano d'investimento SGR, through FITEC, in 2022 invests in FRIEM with a minority shareholding to sustain and accelerate the growth.

Family founder

FRIEM Brasil
San Paolo

FRIEM Indonesia
Jakarta

FRIEM America Inc.
Chicago, IL

FRIEM Chile S.p.A.
Santiago

FRIEM Germany GmbH
Bonn

DynAmp,
Columbus, OH

High Accuracy DC
Current measurement

DYNAMP: high current measurement equipment

In October 2022, FRIEM acquired DynAmp (OH, USA) to boost its presence in North America and solidify its tech leadership.

Dynamp's equipment is installed in Electro Industrial plants located in more than 100 Countries Worldwide.

Exclusive technology to measure direct current up to 100x kAmps, with accuracy up to 0,1%.

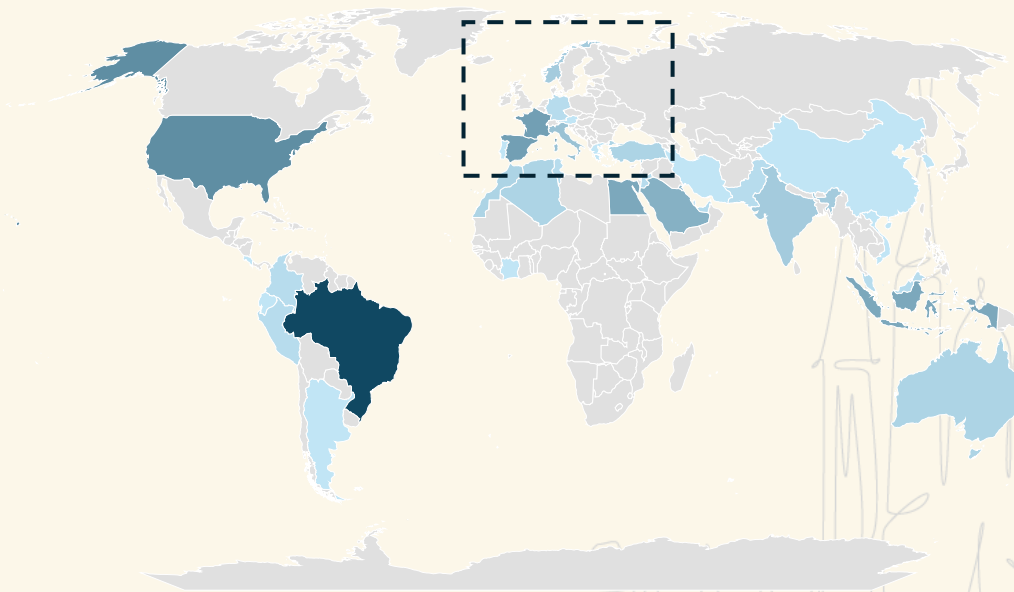
DynAmp

FRIEM CA installed based in Europe (2015-2025)

Rectifiers delivered in the last decade (Chlor-Alkali only)

- Units: 35
- Average electrolyser current: 20 kA DC
- Network reaction per rectifier: mostly 12 pulse
- Total installed power: 583 MVA
- Semiconductor: thyristor
- Units size range: from 20 to 500 tpd of Cl_2
- Total installed capacity: 1,2 M ton / year of Cl_2

Installed base 2015-2025
Chlor alkali



Rectifier units

1 19

Source: FRIEM's analysis – Equivalent Installed Base Production Capacity

Sustainability and ESG

Supporting clients' Net-Zero strategies through energy-intelligent solutions

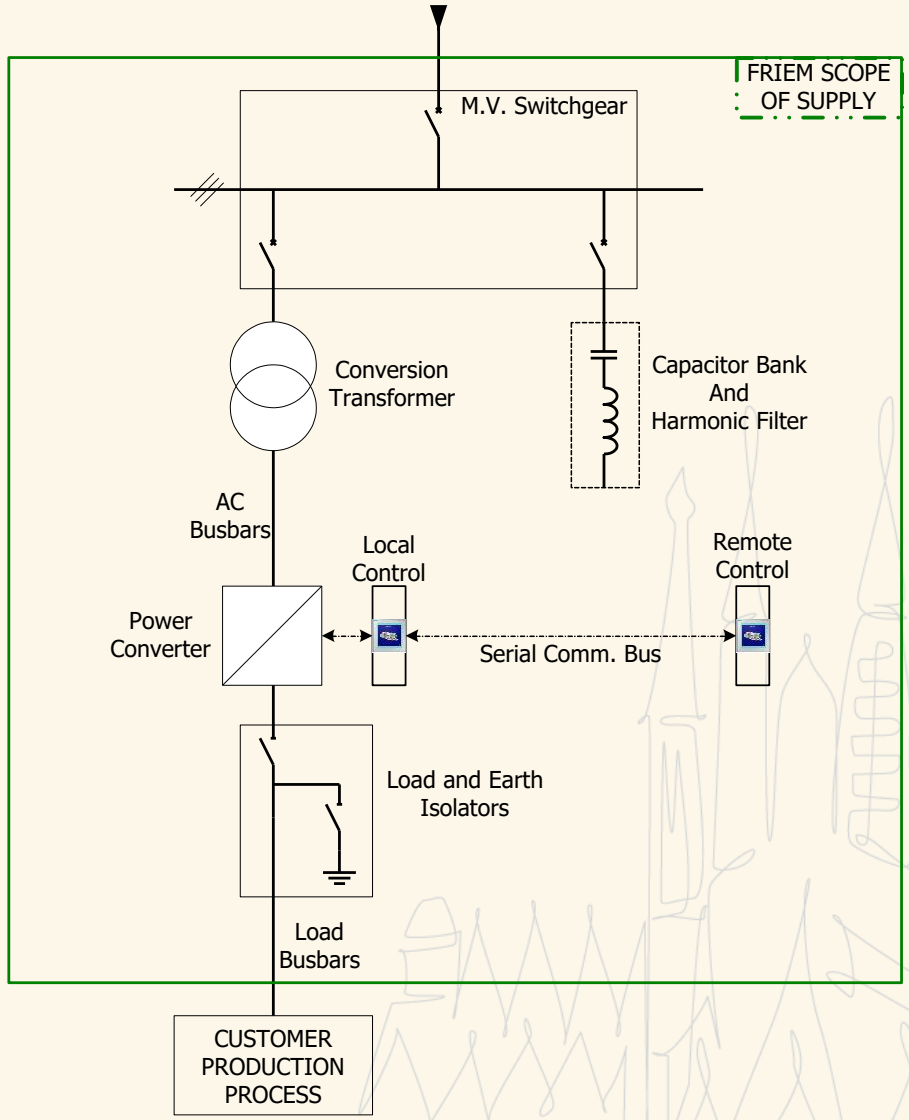
- LCA Cradle to Grave of a power rectifier rated 24 MW
  - **Carbon footprint: 765.424 kg CO2eq/year**
  - Use of eco-friendly materials, low-loss components, and recyclable packaging
  - 60% of the aluminum is recycled

LCA Reference standards: ISO 14040:2021, ISO 14044:2021, ISO 14067

Scope of supply in chlor-alkali

Complete rectifier units: from HV switchgears up to electrolyzers

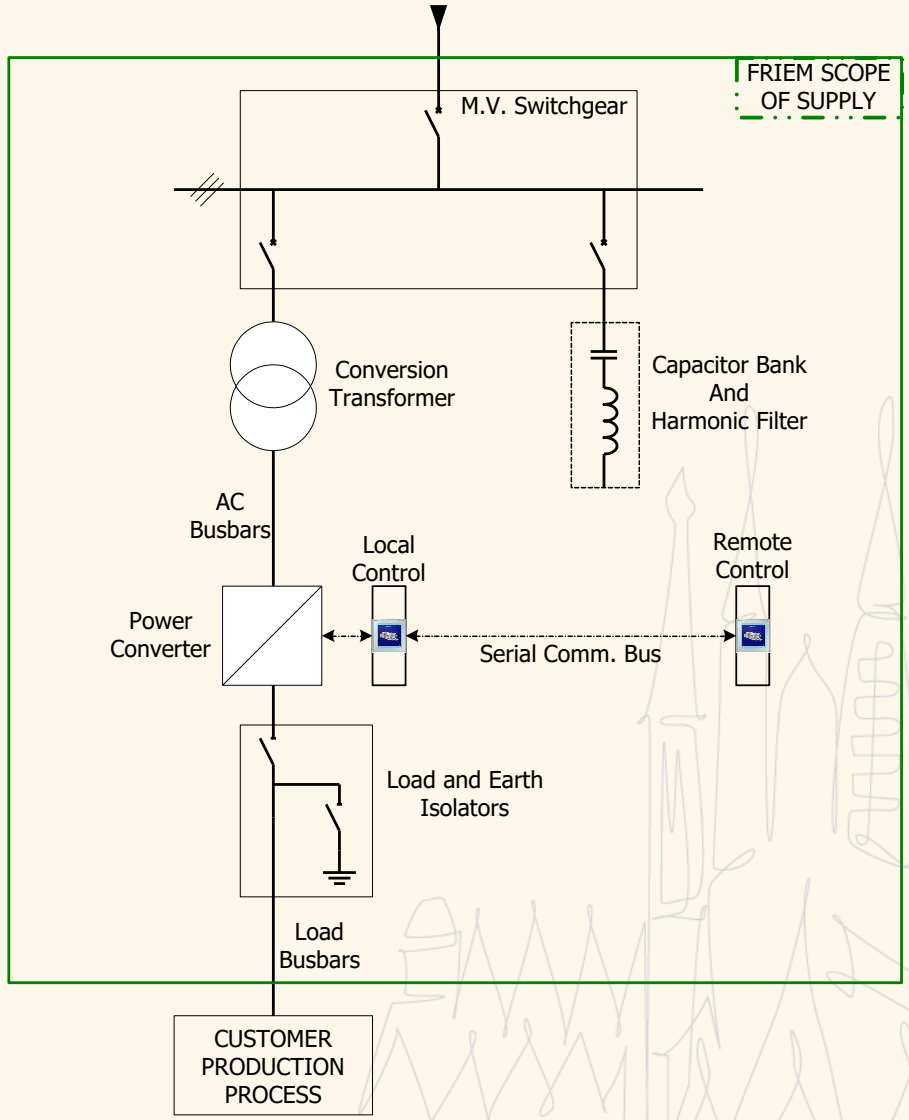
- Rectifier Transformers
- Rectifier Units (Power, Control and Cooling sections)
- High current Busbar Systems
- No Load / On Load Isolators
- Outdoor Containers
- Capacitor Banks and Harmonic Filter Systems
- Interface to DCS and Plant Control Systems
- Polarization rectifiers and premag units



Scope of supply in chlor-alkali

Typical characteristics and unit rating for chlor-alkali

- DC Current: up to 60 kA
- DC Voltage: up to 1000 V
- DC Power: up to 60 MW
- Circuit topology: bridge, double bridge, double star
- Semiconductors: thyristors, diodes
- Reaction on the net: 6, 12, 18, 24 pulses
- Applicable Standards: IEC, ANSI, UL, EAC



Energy Efficiency & Power Quality

High **power conversion efficiency** (typically >95%) as a driver of OPEX reduction.

Managing **harmonics, power factor correction**, and **grid stability**.

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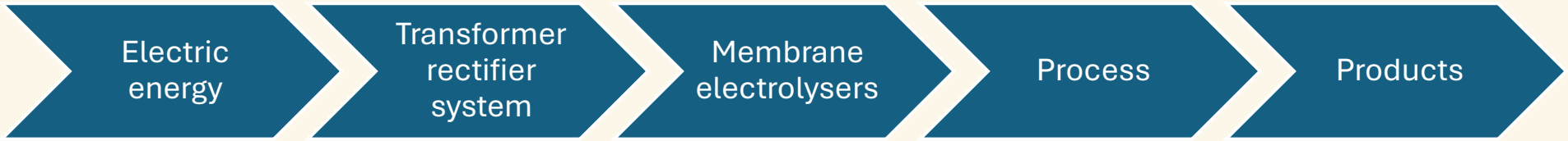
Importance of Rectifiers in Chlor-Alkali production

All electric energy passes through the trafo-rectifiers before feeding the electrolysis



- Electricity is the main raw material for Chlor-Alkali production (approx. 50%-60% of the variable costs).
- 1% higher efficiency in a 10 MW unit* saves up to USD 100k per year
- High power conversion efficiency (typically >96%) is a driver of OPEX reduction

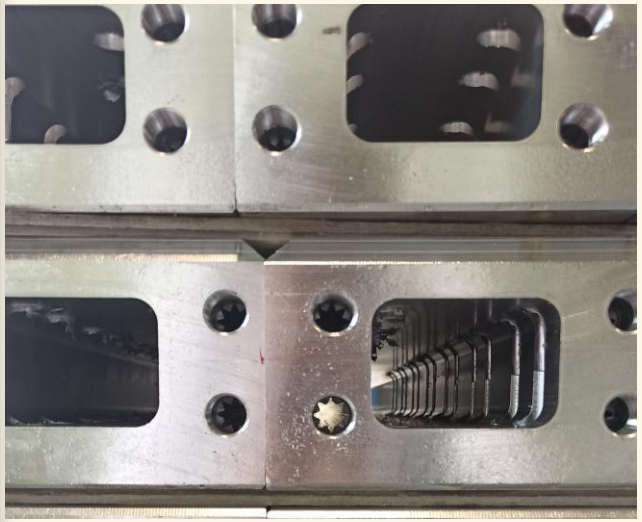
** i.e. 20 kA – 500 V DC*

Answers to the growing demand for energy efficiency

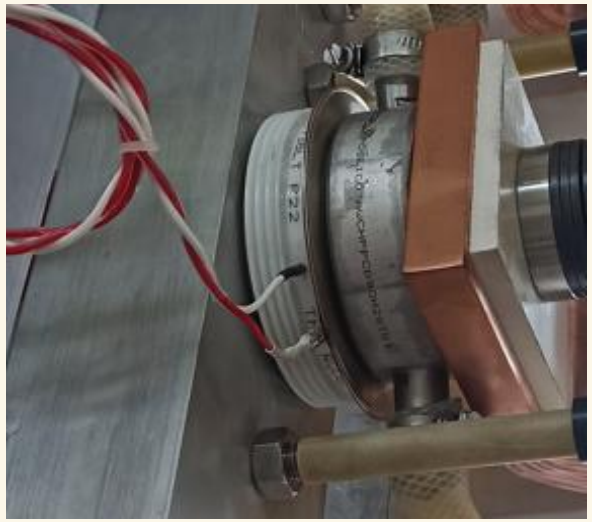
Electrical losses are proportional to the square of the current and influenced by the operating temperature

- $P = R I^2$
- $R = Ro (1 + \alpha \Delta T)$ where Ro is the original resistance (20°C), and R is the resistance after the temperature change.

Patented aluminum profile

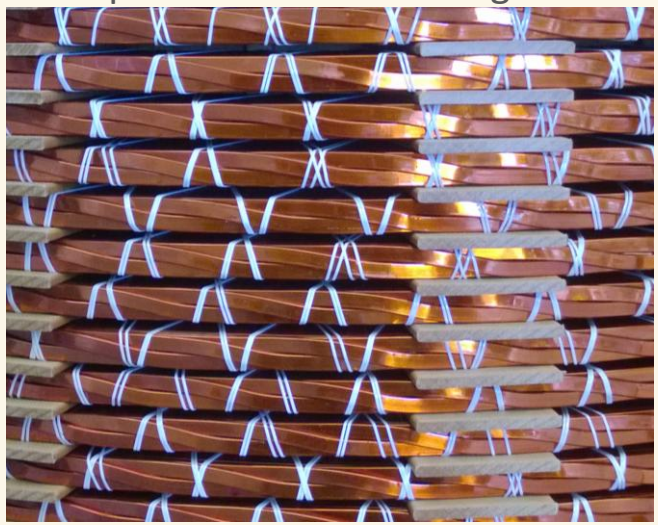


Reduced junction temperatures

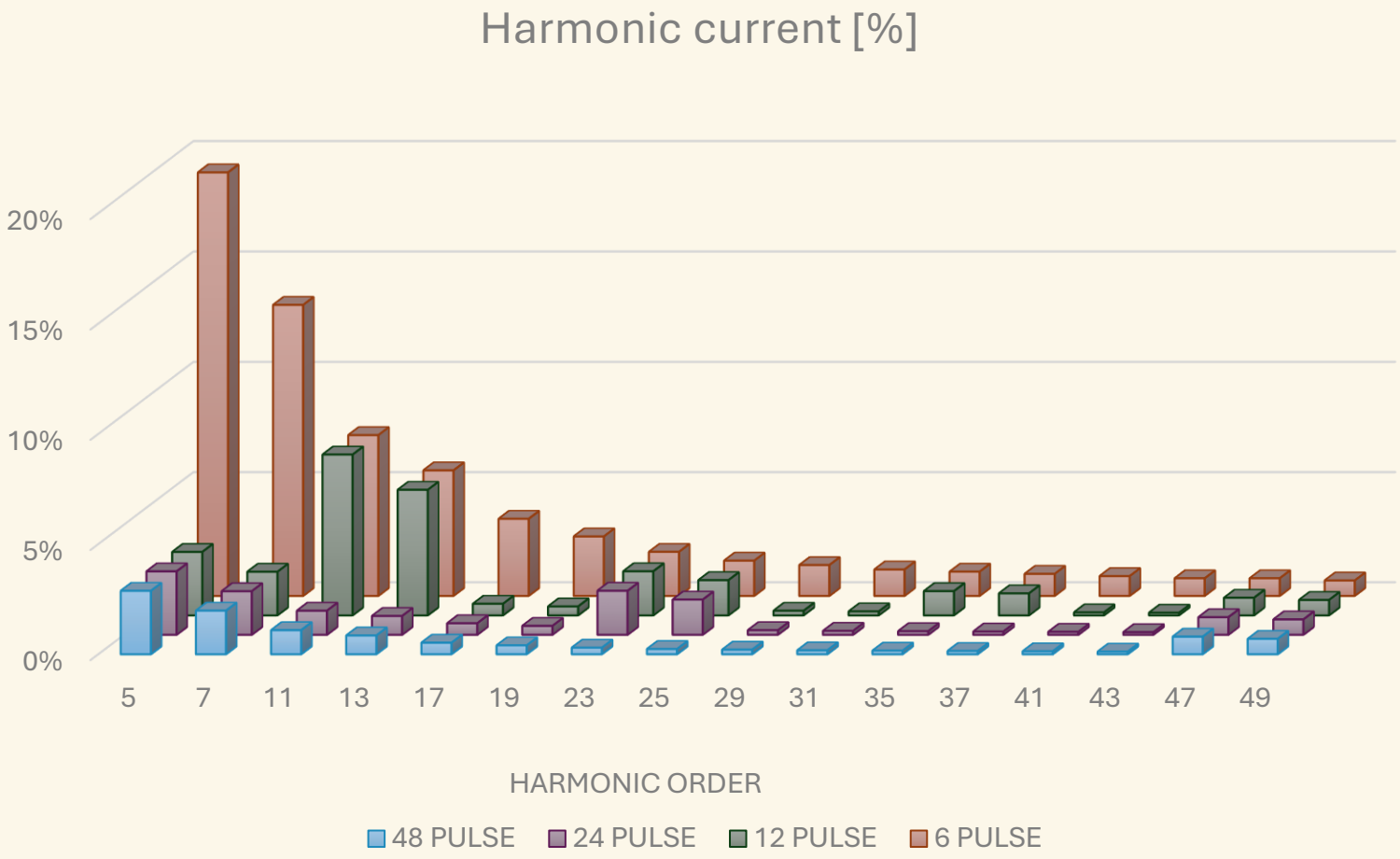


Reduced contact resistance

Transposed cable LV windings



Typical harmonic current distortion generated by a three-phase Silicon Controlled Rectifier system



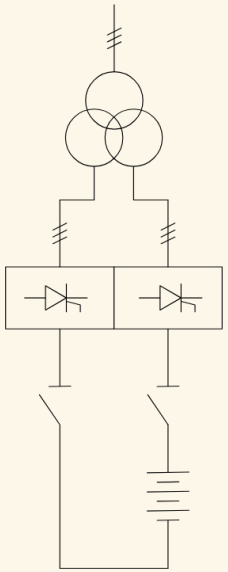
- TDD 6 pulse : 25,7 %
- TDD 12 pulse : 12 % → - 50%
- TDD 24 pulse : 3,8 % → - 85%
- TDD 48 pulse : 2,8 % → - 89%

Source: IEEE Std 519-1981/1992/2014, IEC 60146-1-1 2009, FRIEM Databook.

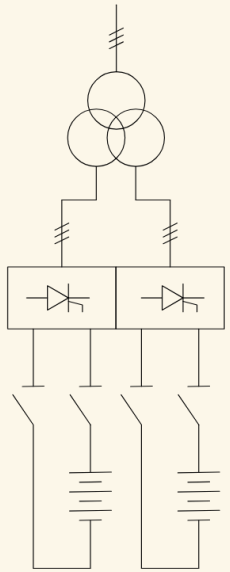
Topologies adopted by EU producers

EU installed based (2015-2025)

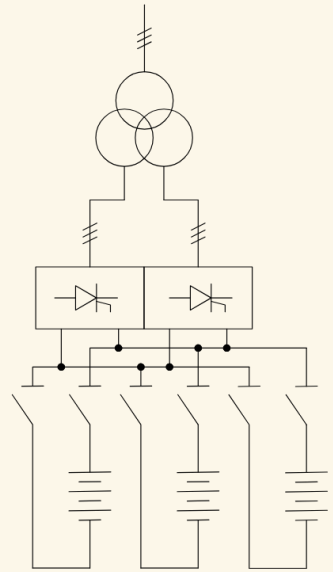
One T-R unit (12 pulse)
One electrolyser



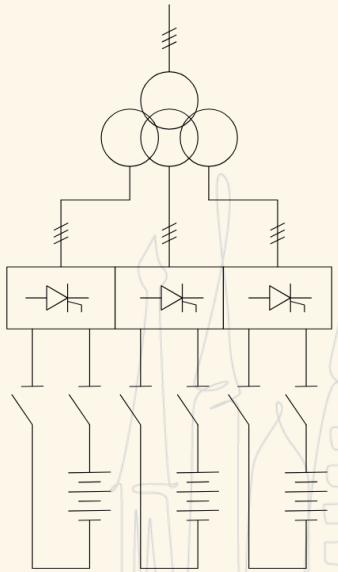
One T-R unit (12 pulse)
Two electrolysers



One T-R unit (12 pulse)
Three electrolysers



One T-R unit (36 pulse)
Three electrolysers



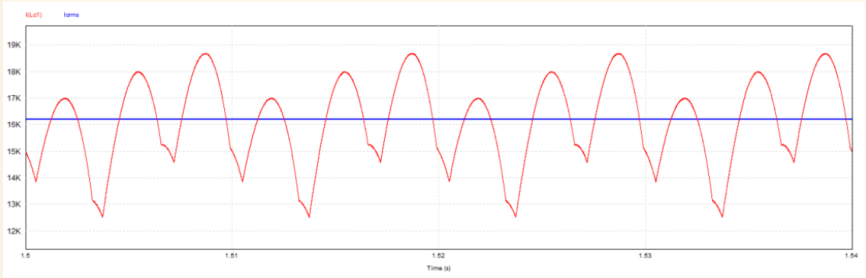
Adoption rate	30%	45%	12%	13%
Advantages	• Flexibility, availability • Low DC ripple • Up to 160 TPD *	• Flexibility • Availability • Up to 500 TPD *	• Cost-effective • Low DC ripple • Up to 200 TPD *	• Cost-effectiveness • Low harmonic distorsion • Up to 430 TPD *

**Equivalent Cl^2 production capacity per order*

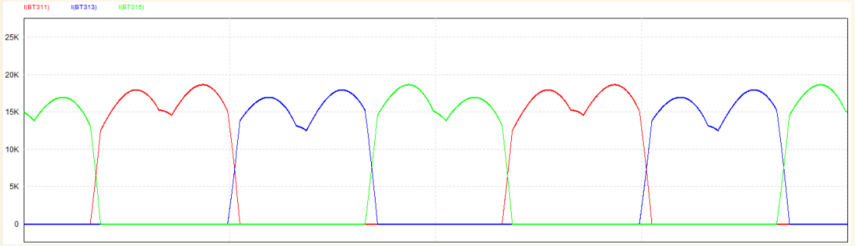
Managing harmonic distortion and PF

Design, supply and simulation of HF improvement and PF correction systems to mitigate the effects of the non-linear loads (rectifiers) in the network.

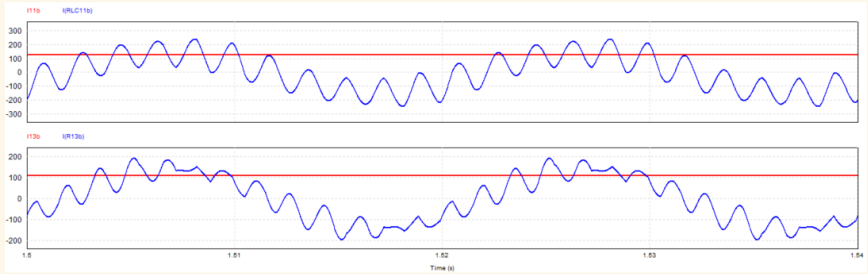
DC current 6 pulse bridge



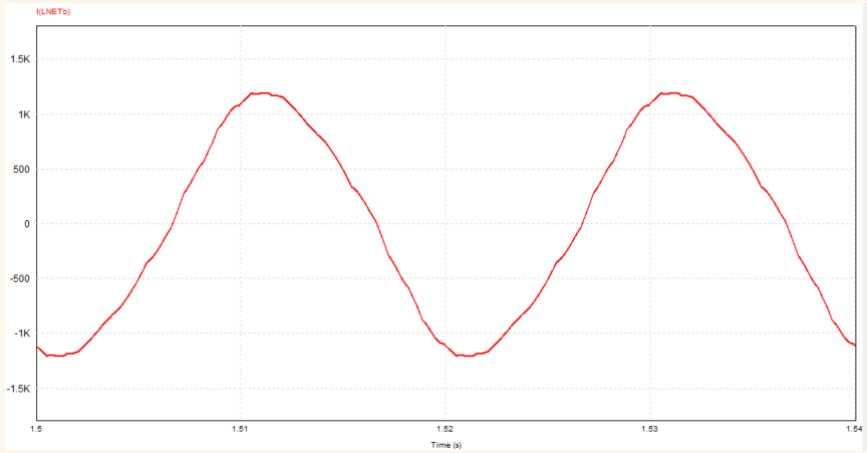
SCR current in 6 pulse bridge



Current in the harmonic filters



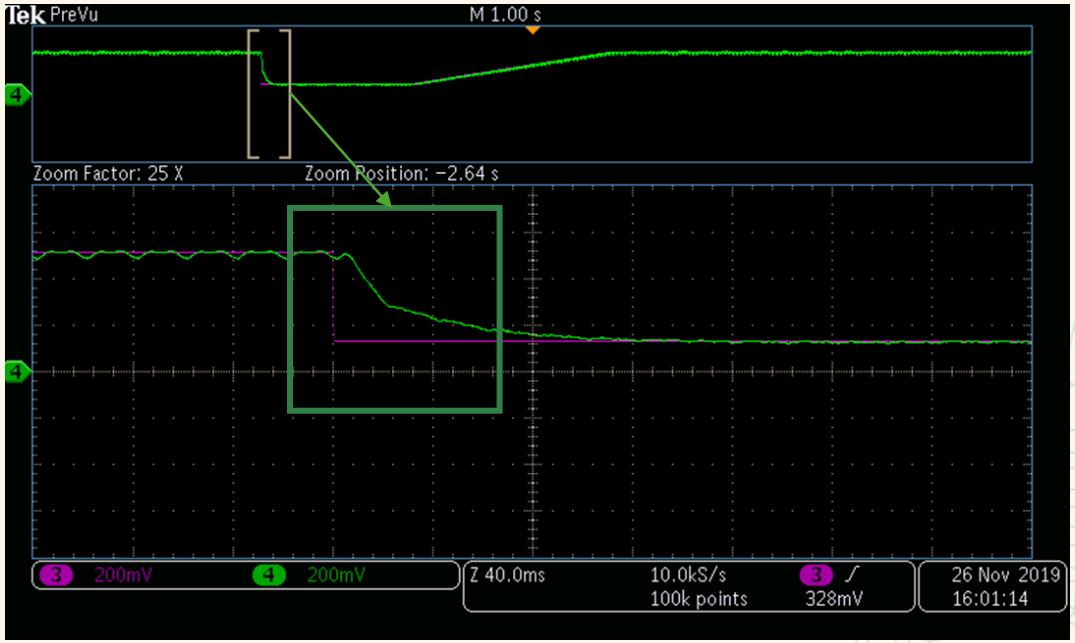
Current from the M.V. power supply



Managing load variation

Load shed

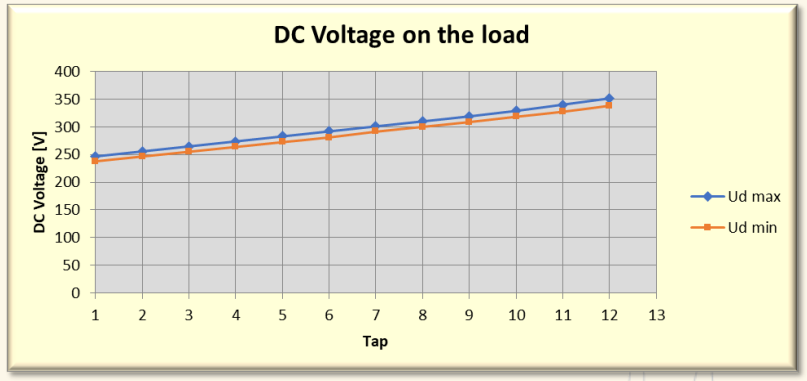
- **Purple**: Reference current imposes current reduction of 75%
- **Green**: Actual DC output current
- The current switches from setpoint 1 to setpoint 2 in less than 100 ms avoiding overshoot phenomena
- Once the signal is released the current returns to previous setpoint with an adjustable ramp

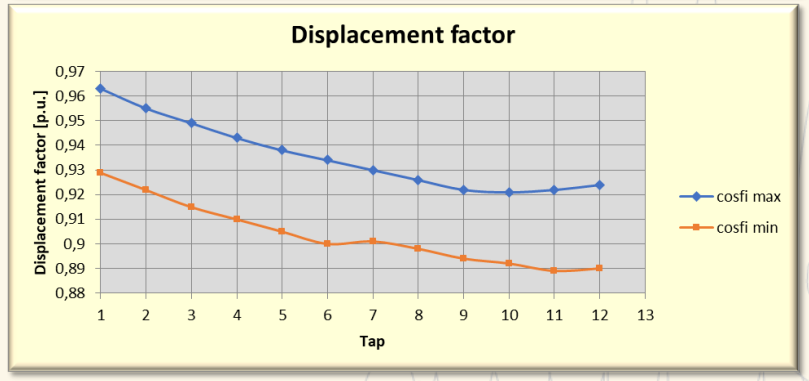


Managing load variation

Tap changer

- On Load Tap Changer (OLTC): regulates voltage without switching off the transformer.
- It keeps PF>0,89 over the load curve
- Used in 85% of last transformers delivered





Reliability and Uptime

Importance of robust design and customized cooling systems (air, water, oil) for harsh chlor-alkali environments.

Redundancy architectures and failure mitigation strategies

Case studies demonstrating >99.5% availability.

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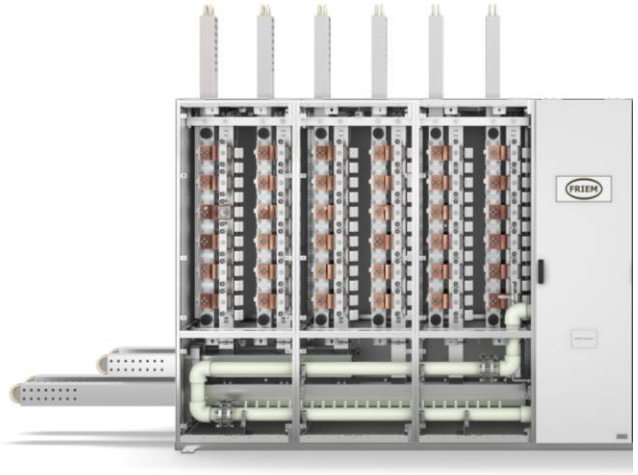
Robust design and customization: rectifier



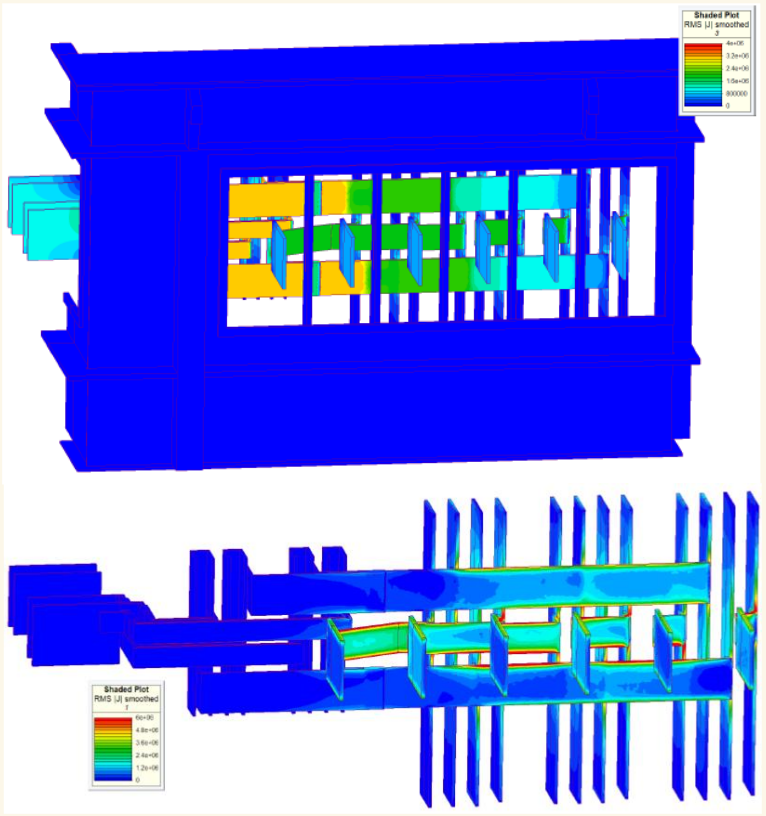
Power section
Where the AC/DC conversion happen, designed to withstand continuous load and to reduce the operating temperature on key components

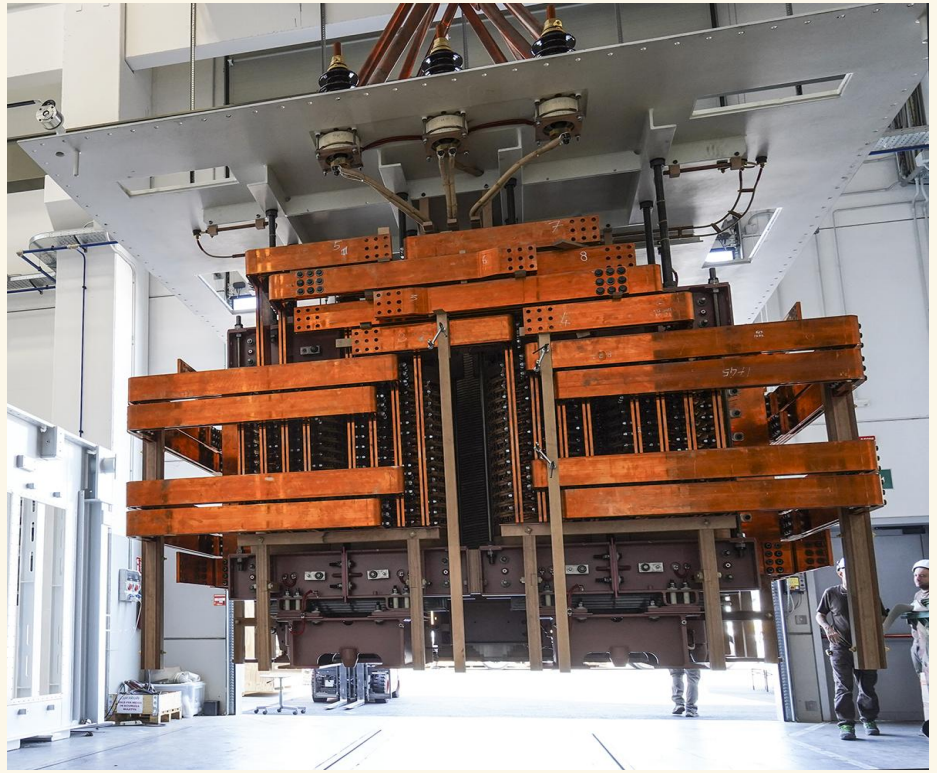
Cooling section
The cooling system is properly designed to dissipate the losses of the rectifier during operations, and it works with deionised water in closed loop

Control section
Designed to monitor and protect the unit and based on the combination of the FRIEM digital current regulator DRP 7.0 and a local PLC for the interface with the DCS

Robust design and customization: transformer

Design review, production stage checks and final tests according to IEC 60076



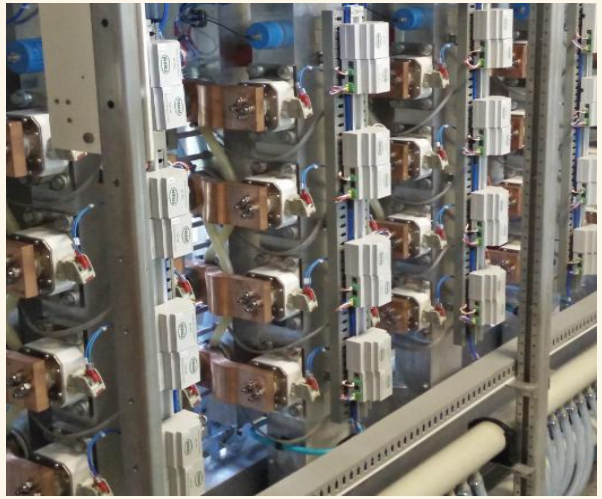


FRIEM conducts transformer’s design reviews per Cigre 529 and IEC 61378-1 standards

Redundancy architectures and failure mitigation strategies

Production process is continuous 24x7 and 365 days per year, it requires high availability and reliability

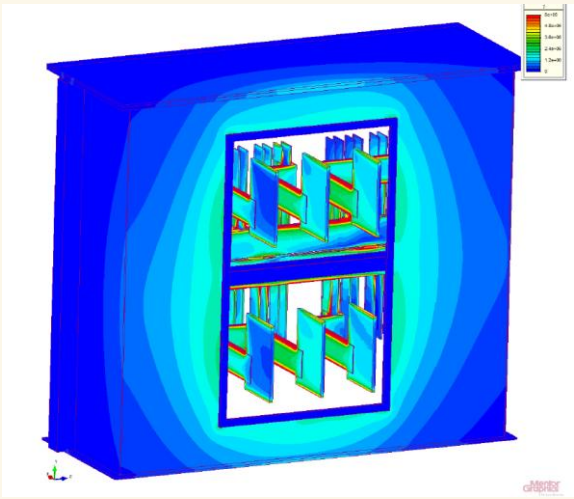
N-1 fuse-SCR redundancy



HEX/pumps redundancy junction temperatures

Digital Current Regulator DRP-7 (Proprietary)

Thermal design



Case study

Analysis performed in partnership with a *confidential EU customer* on 8 FRIEM's transformer-rectifier units operated in their plants from 1991 to 2019

Year	Ref. Number	Start-Up Date	Hours of operation	N° Units	Number of failures during operation	Mean Duration per Failure [h]	Total outage [h]	Total hours
1991	E312-a	01/06/1992	278.208	1	4	5	20	278.208
2001	E391	31/10/2001	195.672	1	2	1	2	195.672
2016	E602	01/06/2017	59.064	1	0	0	0	59.064
2016	E603	01/06/2017	59.064	1	0	0	0	59.064
2017	E631	01/06/2018	50.304	1	0	0	0	50.304
2018	E651	01/06/2020	32.760	1	1	4	4	32.760
2019	E678	01/06/2021	24.000	2	1	2	2	48.000
			699.072	**8**	**8**	**12**	**28**	**723.072**

Notes:

- Annual oil analyzes
- Annual inspection/maintenance
- Redundancy architecture
- FRIEM Service contracts 24/365
- Temperature maintained within the range recommended by FRIEM
- Spare parts available on site

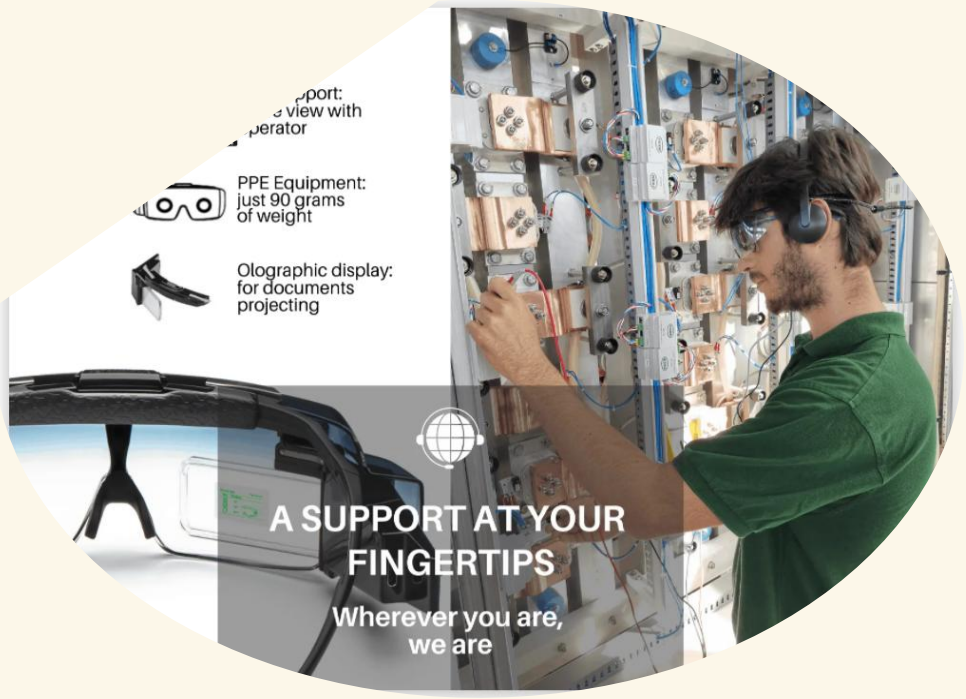
Failure rate $\lambda = \frac{Shut\ down\ events}{Total\ hours\ of\ operation} = 1{,}1\ x\ 10^{-5}$

Availabity: > 99 %

After sales support

Our vast range of services help in reducing the lifetime costs of equipment and plants, beyond increasing their performances and efficiency. Thanks to our skilled technicians, we reach rapidly the plants or assist remotely our customers.

- FAILURE PREVENTION
- REVAMPING (ALL RECTIFIER BRANDS)
- REMOTE ASSISTANCE & DIAGNOSTIC
- ASSISTANCE 24/7
- TIMELY ON-SITE INTERVENTION
- PERFORMANCE IMPROVING



FRIEM: Global reach

#9 Service Centres

Milan · Columbus · Sao Paulo
Jakarta · New Delhi · Lima ·
Santiago Adelaide · Dammam

#5 Subsidiaries

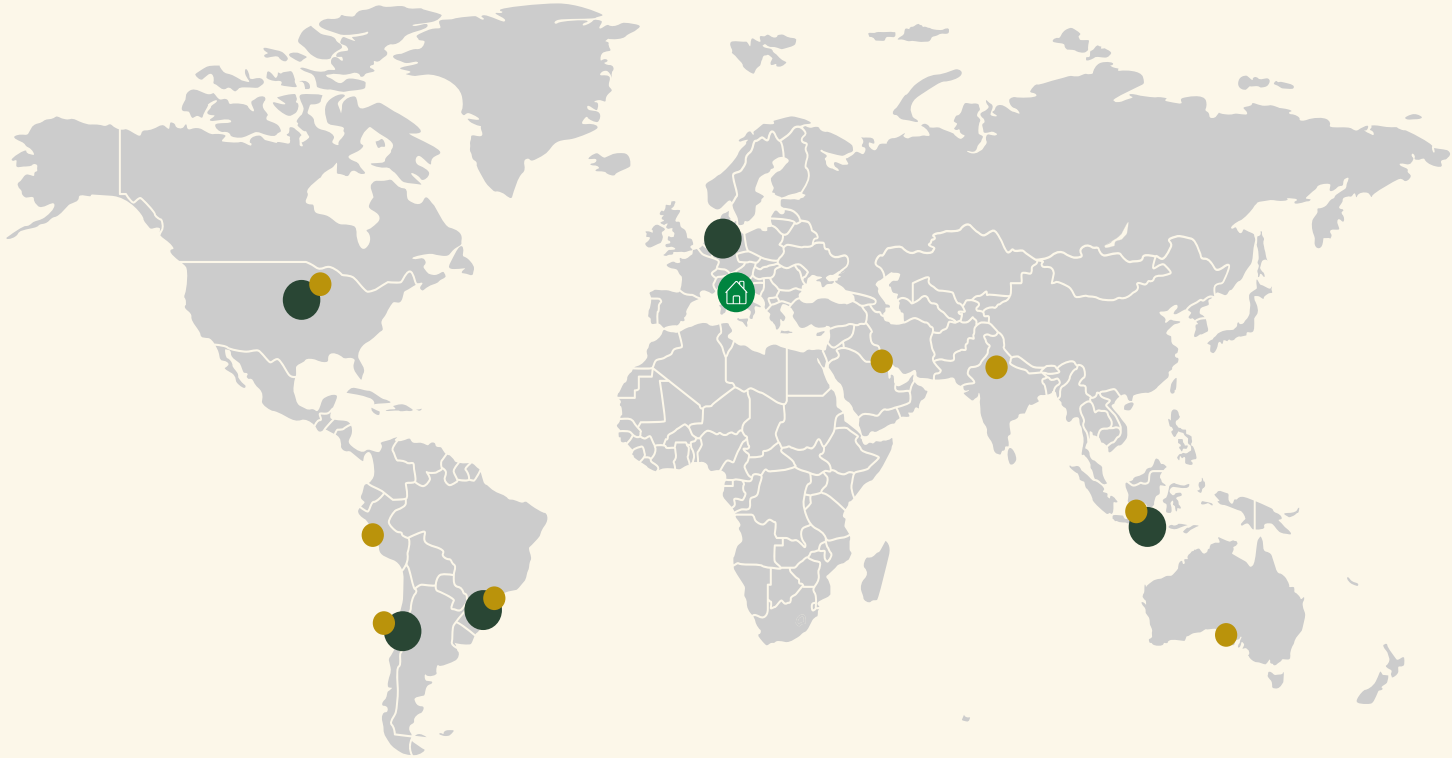
FRIEM America, Chicago

FRIEM Brazil, San Paolo

FRIEM Indonesia, Jakarta

FRIEM Germany, Bonn

FRIEM Chile, Santiago



 # 5 Continents # 27 Countries # 24 Sales / After sales Reps

Thank you for your attention

Maurizio Stucchi

Head of Industry

FRIEM S.p.A.

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