Hydrogen Solutions Guide

of the electrodigital industry

Edited by GIMELEC

As part of its partnership with France Hydrogène
Engagée pour la transition écologique

Power Supply for Electrolysis

Jan. 2025

Introduction

About the GIMELEC Hydrogen Commission

GIMELEC Hydrogen Commission brings together more than 50 manufacturers and solutions providers active across the entire hydrogen value chain, from production to transport, storage and use (industry, mobility, H_2-to-Power, etc.). Their solutions allow project developers to optimize the operation, safety, costs and environmental footprint of hydrogen installations.
https://gimelec.fr/hydrogene

About this guide

This publication is intended for project developers and integrators. It has been redacted by GIMELEC as part of its partnership with France Hydrogène. **The first part is a "white paper"** identifying the challenges and constraints for electrolyser power supply; the second part presents the solutions to meet them and is a directory of GIMELEC companies.
GIMELEC companies offer solutions for electrolyser power supply, automation and instrumentation. This part of the guide is dedicated to power supply for electrolysis. Find the two other sections at the following link.

About GIMELEC

GIMELEC brings together companies from the French electronics and digital sector. Our 210 members design, manufacture and deploy electrification, automation and digitalisation solutions for industry, buildings, mobility, energy and digital infrastructures.
https://gimelec.fr

About France Hydrogène

With 450 members, France Hydrogène brings together the players of the French hydrogen industry along the entire value chain: large industrial groups, SMEs, start-ups, laboratories and research centres, associations, competitiveness clusters and local authorities.
GIMELEC is a partner of France Hydrogène and this document follows and complements the Panorama of Hydrogen Solutions published by France Hydrogène.

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POWER SUPPLY OPTIONS

Medium voltage (MV) grid connection (HTA network)

ENEDIS

Standard OEM connection for small H2 projects.

Focus in France

High voltage (HV) grid connection (HTB network)

Rte Le réseau de l'intelligence électrique

HV grid connection for massive H2 projects requires anticipation.

Minor focus

Direct electrical connection to distributed renewable assets

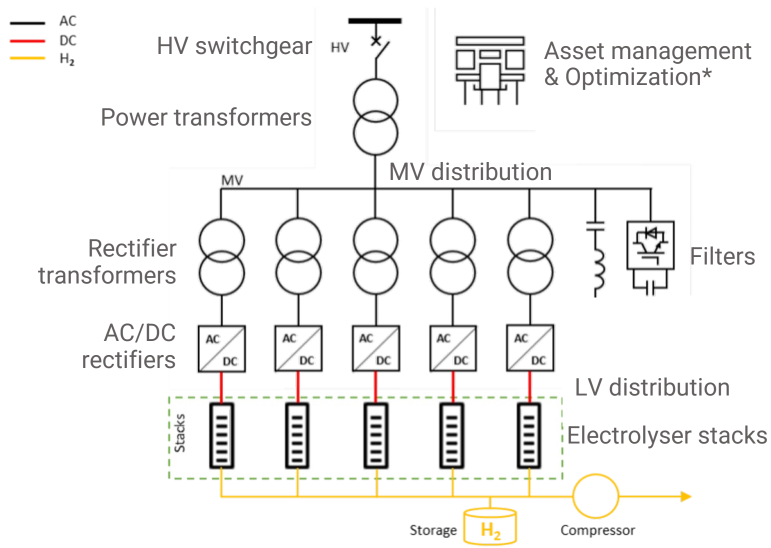
Very few facilities of this kind in France because of low-carbon grid electricity. Hybrid architectures are possible (see p.11)

HV GRID CONNECTION CHALLENGES

"Ensure safe and reliable electrolyser performance in compliance with existing and future grid codes"

Electrolyzers need electrical power input to operate. They can be directly connected to a renewable energy source (typically wind power) or to the grid. In case of grid connection, they can be connected to medium voltage (MV) grid for low power, but **with increasing electrolyser loads, a high voltage network (HV) connection is required.** HV Grid connection requires several components to both provide appropriate DC power to electrolysers and protect grid quality.

Electrolyser HV grid connection setup



Credit : Hitachi Energy
Nota : *) See section « Automation »

HV Grid connection challenges

The electrical substation **ensures efficient power conversion** to power electrolyzers while **connecting safely and timely to the grid** in full compliance with grid code requirements (harmonics, power factor etc.)

Electrolyzers are **important electrical loads generating pollution and creating grid unbalance.** Current grid codes don't hold H2 project developers accountable for cleaning and balancing the electrical grid, but future grid codes will require them to contribute to it at the substation level. This grid pollution and unbalancing issue is still widely underestimated today and is crucial for H2 sector growth -> see p.11-13 the details on harmonic pollution.

The electrical substation only accounts for 1-2% of failure cases in hydrogen electrolysis plants but represents as much as 25% of all production losses.

Unproper design may generate back-current within the transformers, requiring to change the whole substation in the worst cases, or unnecessarily high switching frequency with various consequences such as early equipment replacement, penalties, grid disconnection…

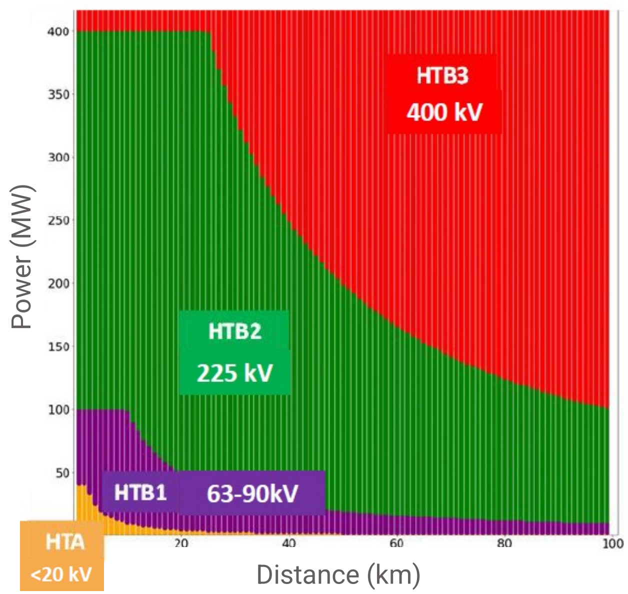
Harmonic pollution, caused by distorted electrical currents, can have detrimental effects on electrical systems : energy loss, higher subscription costs, equipment oversizing, reduced service lifetime, nuisance tripping and installation shutdown.

Optimizing the full power supply system from grid connection down to electrolyzers stack requires an integrated and **holistic approach from design studies until service on site.**

HV GRID CONNECTION CHALLENGES (France)

How to define the connection voltage

Reference connection voltage depends on **the power of the project** and its **distance to the nearest transformer substastion**



A project is connected to the HV grid if its power is higher to 40MW or 100/d, “d” being the distance between the project and the nearest transformer substation to the superior voltage range.

Regulatory thresholds (Decree of June 9, 2020) set the connection voltage.

Sources : RTE

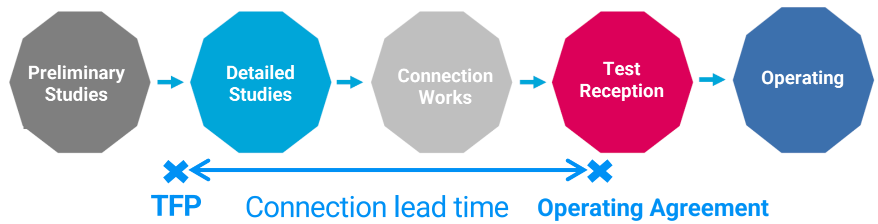
Time required for the connection

RTE Technical and Financial Proposal (TFP) is an important milestone to a hydrogen project, often critical to **validate the Final Investment Decision (FID)**.

The connection lead time is the period between the approval of the TFP and the Test reception and operating agreement.

Connection Voltage	Average lead time
HTB1 (63 or 90kV)	2 to 3 years
HTB2 (225kV)	4 to 6 years
HTB3 (400kV)	6 to 9 years

Delays tend to increase because of the high number of connection demands to the HV grid and the long procurement lead time for some devices (transformers for instance).

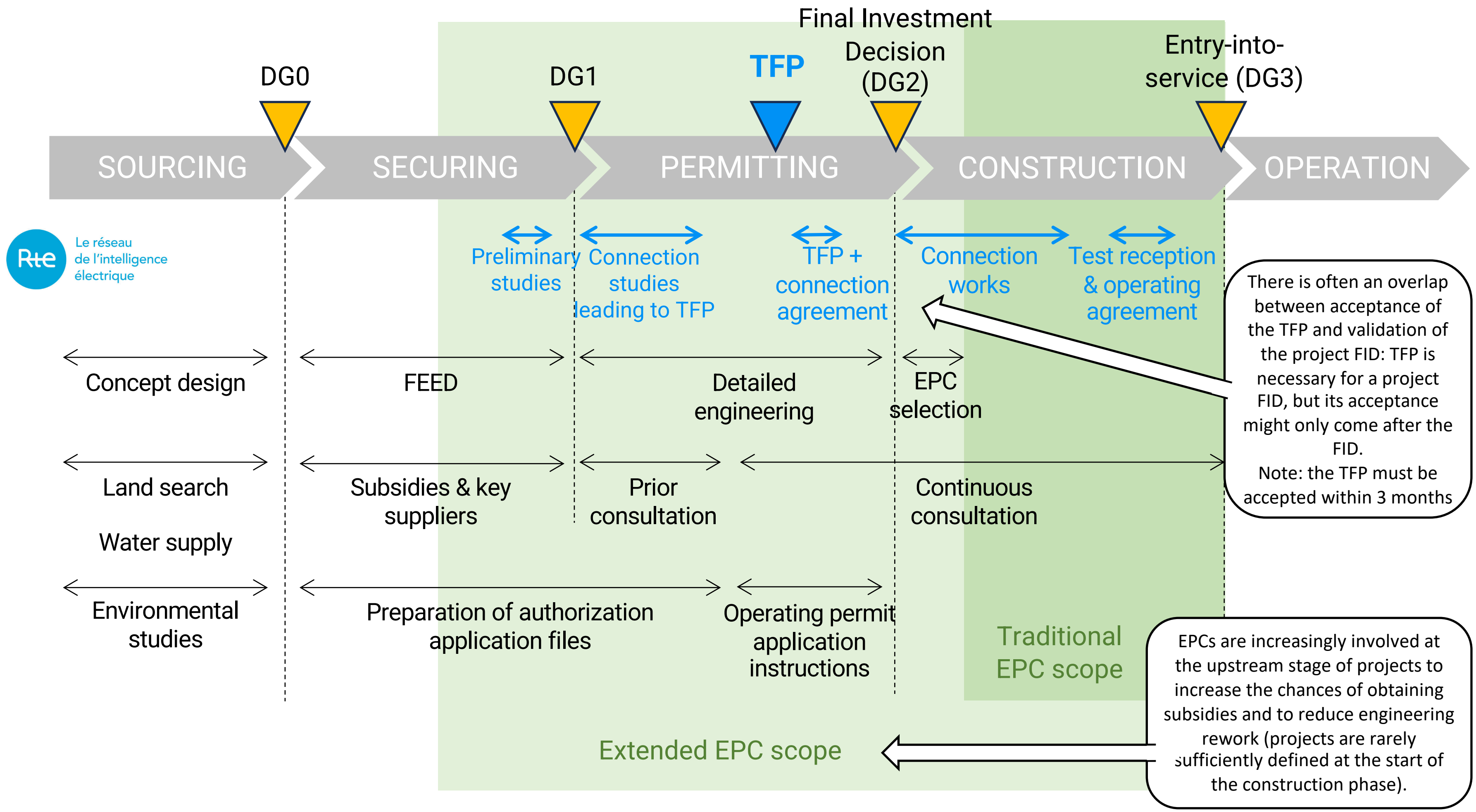


The project developer and RTE can optimize it by working in collaboration, **anticipating devices delivery**.

RTE is also anticipating the **development of mutualized connection infrastructures in some industrial and port areas** (such as Dunkirk, le Havre, and Fos-sur-Mer) in order to accomodate several industries and reduce the connection lead time.

HV GRID CONNECTION CHALLENGES (France)

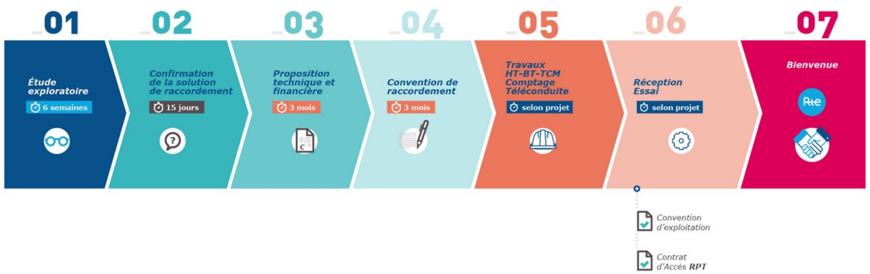
Stages of development of a hydrogen project: EPC scope & grid connection milestones



Note : DG = Development Gate milestone

HV GRID CONNECTION CHALLENGES (France)

Grid connection procedure : main steps (link)



- **Exploratory study**: aims to provide a rapid estimate of the feasibility of the project as well as an order of the cost of the connection solution envisaged and its completion time; the exploratory study, which is not a prerequisite to the connection request, does not bind either party.
- **Technical and financial proposal (TFP):** aims to establish the connection conditions; it presents the solution selected, the consistency of the work, the details of the costs and completion times.
- **Connection agreement:** sets out the technical, legal and financial terms of the connection; it launches the construction phase, guaranteeing financing for equipment orders and work.
- **Grid access contract:** defines the commitments in terms of metering, subscribed power and scheduled interruptions to grid access; also specifies the conditions of responsibilities, pricing and invoicing.
- **Operation and management agreement:** defines the responsibilities of each party to ensure the proper integration of the installation into the electrical system, as well as the operating and management rules to guarantee the safety of property and people.

Technical reference documentation

All the requirements that any electrical consumer connected to the RTE HTB network must observe at the time of connection are detailed in the technical reference documentation, the currently valid version of which (2024) can be consulted at the following link:

https://www.services-rte.com/fr/la-bibliotheque.html

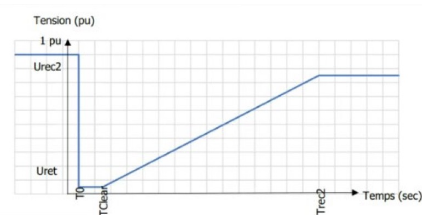
This publication depends on technical requirements defined at the national and European level, in collaboration with ENTSO-E because the grid codes are evolving at the European level. The ACER (Agency for the Cooperation of Energy Regulators) has published a number of proposals that are currently being validated (link).

All hydrogen projects with a power greater than 40MW are affected by these requirements and will therefore have to anticipate the connection time.

Grid Codes Challenges

The GIMELEC Guide currently focuses on harmonic pollution, but other challenges will become pregnant in the following years, for instance LVRT* and short circuit capacity. Specifications are already more stringent in Germany, Spain and Netherlands

-> Update of the Guide to come



Voltage dip

Sources: RTE

Nota : *) Low Voltage Ride Through (LVRT): uninterrupted power supply throughout a short voltage drop

PROJECT LIFECYCLE

DESIGN	PROCUREMENT	INSTALLATION	OPERATION
p. 10-13	p. 14-17	p. 18	p. 19

DESIGN

- **OPTIMIZATION:**
  - → Increase system performance while minimizing overall investment and footprint
- **HARMONIC POLLUTION:**
  - → Selecting power electronics technology to ensure grid code compliance while optimizing investment
  - → Optimizing electrical layout with regards to the grid requirements and operational constraints
  - → Limiting the negative impacts of harmonic pollution

PROCUREMENT

- **HARDWARE:**
  - → Choosing the adequate package of products, systems and or services
- **DIGITAL SOLUTIONS:**
  - → Implement an optimized steering strategy
- **PRODUCTS & SERVICES:**
  - → Choose the package of products and services adapted to the characteristics of the project, the skills and the constraints of the project owner

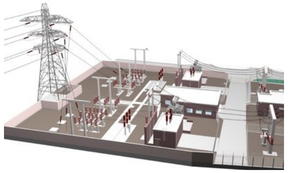
INSTALLATION

- **TECHNICAL INTEGRATION**
  - → Identify the most relevant business model for the project

OPERATION

- **MAINTENANCE SERVICES:**
  - → Maximize availability, optimize overall performance and prevent costly failures

DESIGN / OPTIMIZATION SCOPE



"Increase system performance while minimizing overall investment and footprint"

Feasibility studies & efficiency optimization

Procuring power conversion units from electrolyser OEMs often ends up in selecting non-adapted power electronic triggering potentially unsolvable grid code compliance constraints on separately purchased AC grid connection devices (passive or active filters).

Optimizing the complete power supply system, from grid connection down to stack terminals comes with greater benefits :

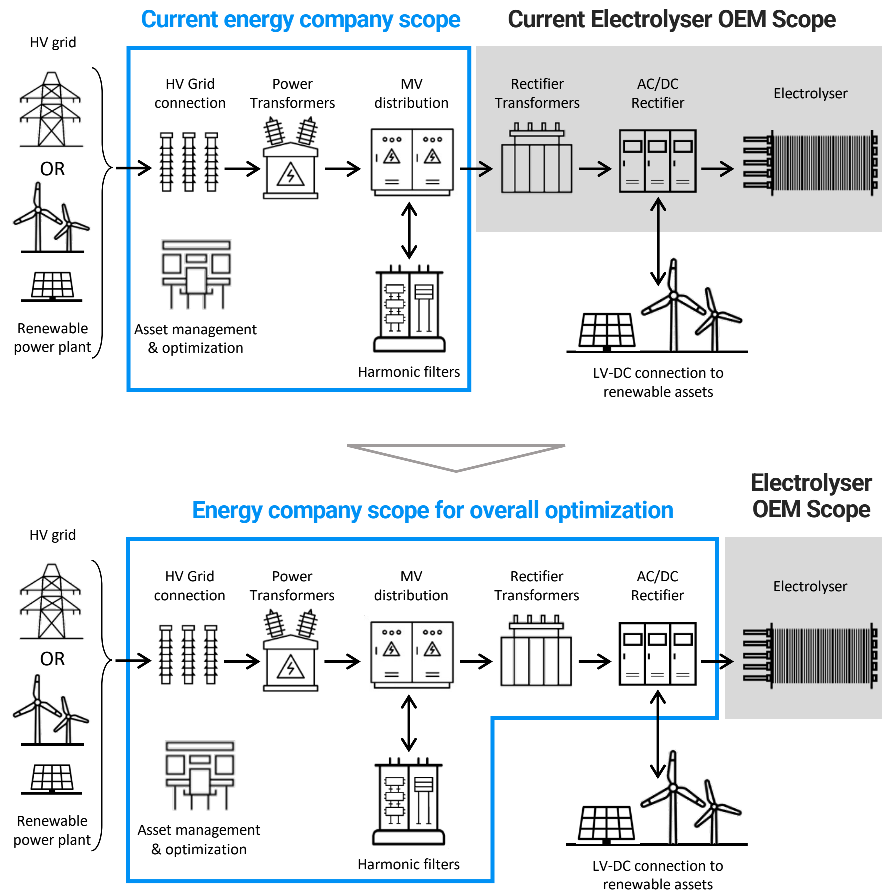
- de-risking plant in relation to grid code compliance and fluctuating renewable power supply
- increasing overall system performance.

But optimizing the complete power supply system requires specific competences and advocates for a **change of perimeter of current suppliers.**

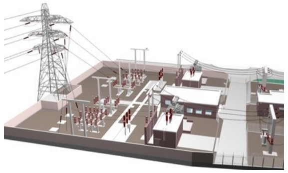
In this new perspective, Energy companies should design the complete power supply from grid connection down to stack terminals, **selecting the optimal hardware technology and design setup.**

Only this way can the power supply system be optimized, hence **securing the overall investment**.

Energy company scope extension for high power electrolysers



DESIGN / HARMONIC POLLUTION (1/3)



"Selecting power electronics technology to ensure grid code compliance while optimizing investment"

The different sources of harmonic pollutions

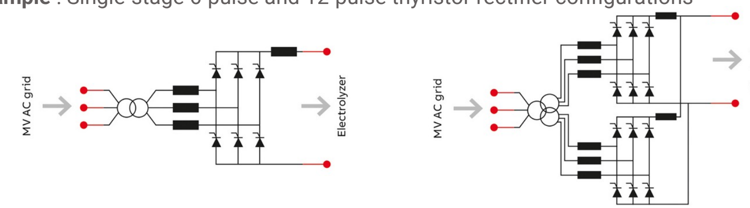
In normal as well in defective plant operations, rectifier technology, stack downtime, variable loads/partial loading strategies or load shedding are all causes for unbalance between the different phases thus generating harmonics (i.e. multiples of 50Hz) in current (Total Harmonic Distortion in current, or THDi) and voltage (THDv) that subsequently impact the network and voltage quality. THDv is very closely monitored by TSOs, which mandate a maximum THDv value on installations.

A distinction is generally made between two sources of harmonic pollution :

1. **The rectifier**: There are 2 competing rectifier technologies: thyristors (opening time control) and IGBT / AFE ("Active Front-End" also called "IGBT supply").

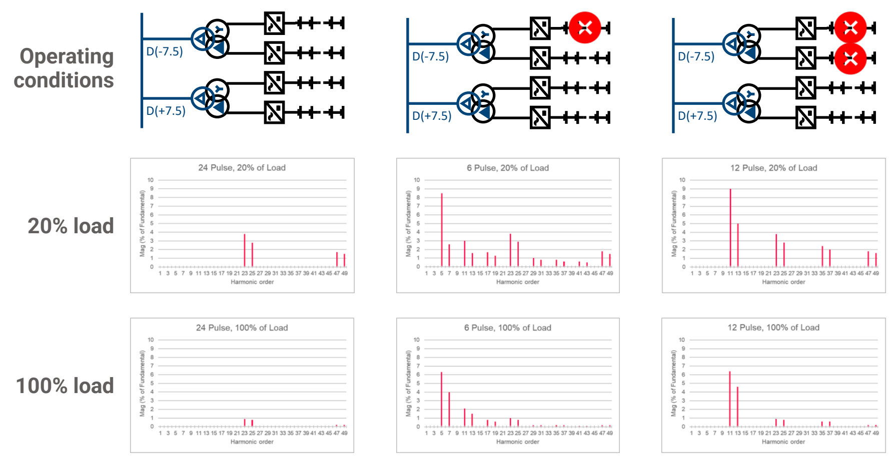
   Thyristor rectifiers are available in 6-pulse, 12-pulse, 18-pulse or 24-pulse configurations. The more pulses, the less harmonics but the number of secondary windings increases proportionally on the transformer's side: 6-pulse → 2 modules in parallel, 18-pulse → 3 modules in parallel, 24-pulse → 4 modules in parallel. When several modules are connected downstream on the same supply feed, one cannot control each module completely independently.

Example : Single-stage 6-pulse and 12-pulse thyristor rectifier configurations



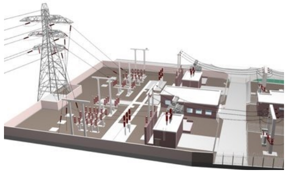
AFE/IGBTs are more dynamic power components which create less harmonic distortion in current but are more costly to purchase than thyristor-based solutions. Using AFE/IGBTs enables THDi below 5% and even below 3% in the best cases.

2. **The imbalance of modules**: when several modules are connected in parallel to the same supply feed, harmonics profiles vary whether all stacks are operational or some are shut-down, whether the system is operating at partial load or full load etc.



Credit : Hitachi Energy, ABB

DESIGN / HARMONIC POLLUTION (2/3)

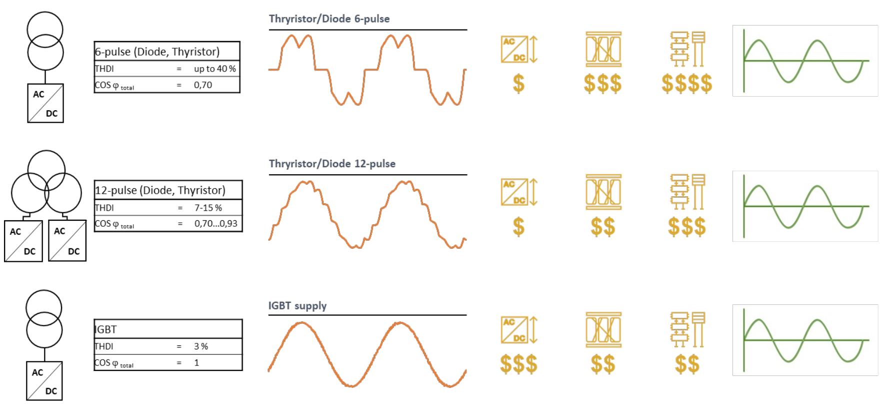


"Optimizing electrical layout with regards to the grid requirements and operational constraints"

AFE/IGBT rectifiers vs. harmonic filters

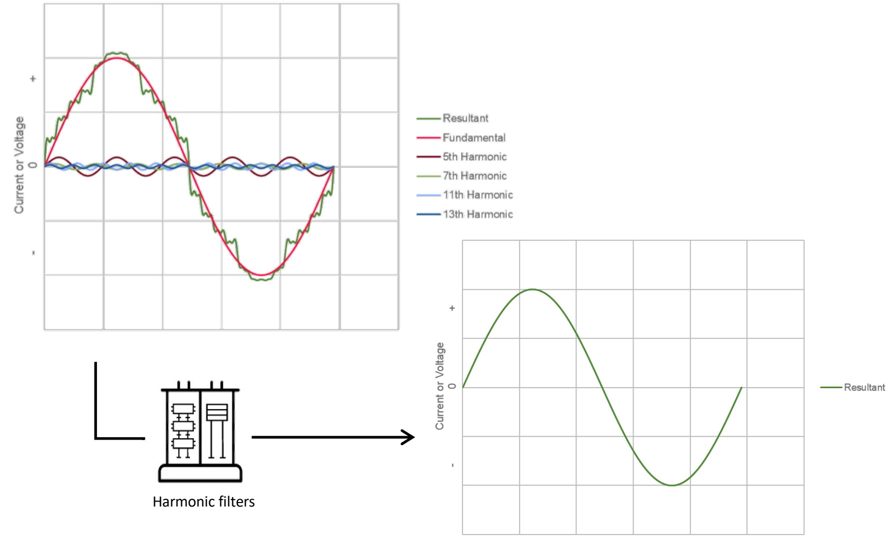
To mitigate harmonic pollution, both low-harmonic rectifiers (AFE/IGBT) or harmonic filters can be used. **There is no general rule** as to which system is most indicated. It's a **case-by-case analysis**: thyristor rectifiers are much cheaper but require that filters be added whereas IGBT rectifiers natively generate very little harmonics but are generally +30-40% more costly than Thyristors on a CAPEX basis. **Only a thorough electrical analysis can determine the best electrical layout**.

The figure below outlines the major design tradeoffs:



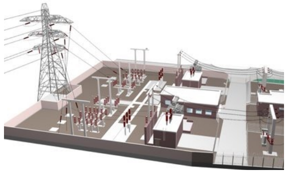
Credit : Hitachi Energy

Properly designed filters adjust the wave form thus improving power supply quality, eliminating nuisance tripping, and reducing stress on electrical systems. They help maintain equipment longevity and prevent costly disruptions.



Special attention should be paid to applications in which hydrogen is produced with renewable energy. The inherent fluctuations of such energy sources will also demand new electrical layouts. Control methods, together with new semiconductor materials such as silicon carbide and novel power converters may result in solutions that are compatible with both the grid and the electrolyser, while simultaneously reducing complexity.

DESIGN / HARMONIC POLLUTION (3/3)

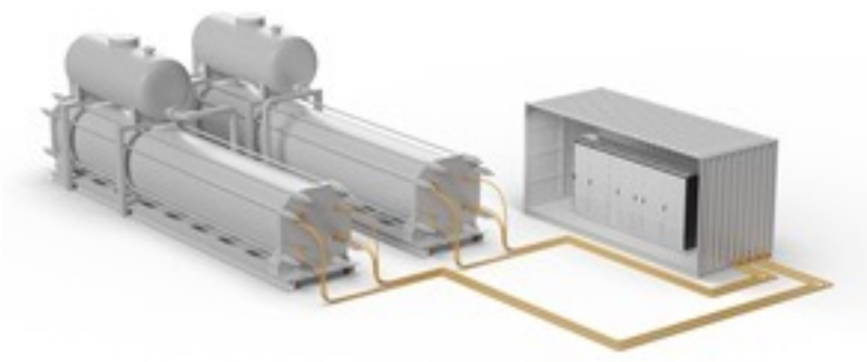


"Limiting the negative impacts of harmonic pollution"

Negative impacts of harmonic pollution

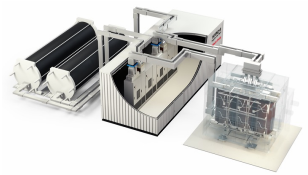
Harmonic pollution, caused by distorted electrical currents, can have detrimental effects on electrical systems. When the design of harmonic filters and power quality equipment falls short, several risks emerge:

- **Grid pollution:** For the moment, the French grid code affects producers more than consumers. The current "pollute and clean" approach is showing its limits because passive filters cause grid instabilities. With the proliferation of large electrolysis plants, TSOs clearly prefer that there be no pollution. Thus, new requirements may be requested for new installations and hydrogen production plants will likely have to participate in stabilizing the network. In this perspective, AFE/IGBT technology will provide grid support services with voltage-frequency modification which thyristor-based solutions cannot.
- **Energy losses:** Harmonics cause additional losses (Joule effect) in conductors and equipment.
- **Higher subscription costs:** The presence of harmonic currents may require a higher subscribed power level, leading to increased costs. Utilities may also charge customers for major sources of harmonics.
- **Equipment oversizing:** Derating of power sources (such as generators, transformers, and UPS) necessitates oversizing. Conductors must also account for harmonic currents, and the skin effect increases conductor resistance with frequency.
- **Reduced service lifetime:** Equipment service life significantly decreases to the increase of the total harmonic distortion (THD). For example, higher harmonics can cause hot spots in transformers, accelerating insulation aging.
- **Nuisance tripping and installation shutdown:** Circuit breakers experience current peaks due to harmonics. Nuisance tripping disrupts operations, resulting in production losses and additional costs to restart the installation.
- **Local network disturbances:** The problem of harmonic pollution is not only a concern for the grid but also for other installations connected on the same premises. Hydrogen consumers having on-site electrolyzers can self-pollute their local electrical network and generate faults elsewhere in their factory for example.



Credit : Hitachi Energy, ABB

PROCUREMENT / HARDWARE (1/3)

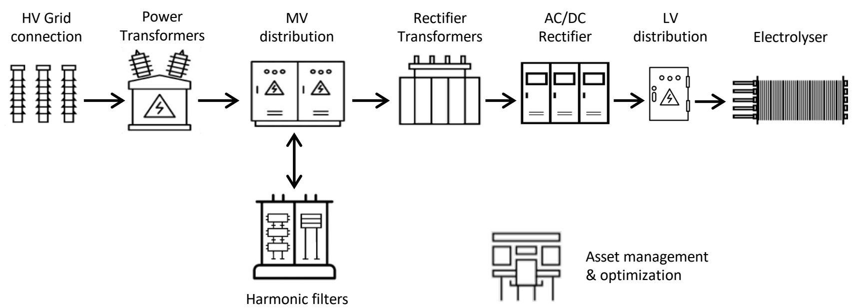


“Choosing the adequate package of products, systems and or services”

Main electrical equipment packages

When procuring a power supply system, there are five main equipment packages to consider : switchgears / HV products, power transformers, rectifiers and filters.

For the sake of simplicity, other ancillary hardware (electrical distribution, AC and DC busbar systems etc.) are not detailed here.



SF6

UE 2024/573 F-Gas Regulation bans Fluorinated greenhouse gases (F-gases) and ozone depleting substances (ODS)

Voltage	Banning date for new installation
Ur ≤ 24 kV	2026
24 kV < Ur ≤ 52 kV	2030
52 kV < Ur ≤ 145 kV & Isc ≤ 50 kA	2028
Ur > 145 kV & Isc > 50 kA	2032

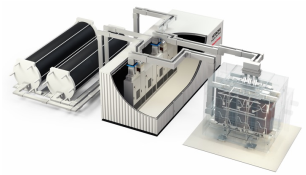
Gas-Insulated Substations (GIS / PSEM in French) use a significant amount of SF6, and house SF6-insulated circuit breakers, busbars and monitoring equipment.
Other pieces of equipment using smaller amounts of SF6 include disconnectors and ground switches that use SF6 primarily for insulation

Derogations possible according to the number of solutions available on the market and the gas used

Number of years after ban	1	2	3	4
SF6 allowed	None supplier with GWP <1000			
GWP <1000 allowed	None or only 1 supplier without fluorinated gas		None supplier without fluorinated gas	
Without fluorinated gas	OK			

From 1st January 2035, the use of SF6 for the maintenance or servicing of electrical switchgear equipments shall be prohibited except if SF6 is proven reclaimed or recycled.

PROCUREMENT / HARDWARE (2/3)



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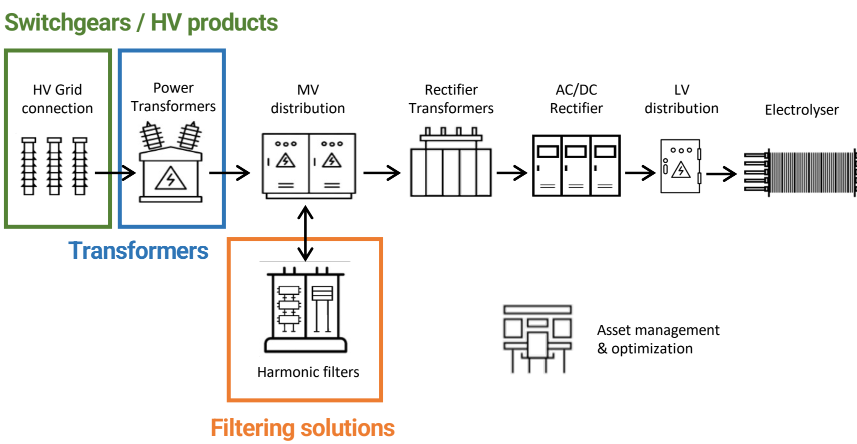


Switchgears / HV products

- AIS / GIS / Hybrid
- Live Tank Breaker LTA
- Disconnecting Circuit-breaker (DCB) LTA

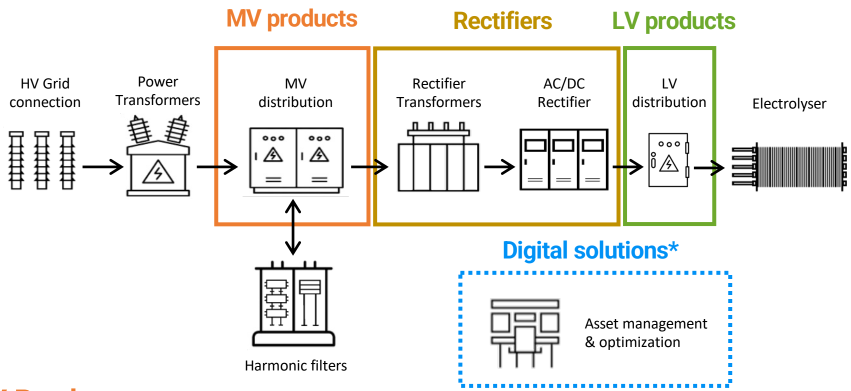
Power transformers

- 24-132 kV
- 132-220 kV
- 220-400 kV

Filtering solutions

- Passive filter: capacitor bank, harmonic filters, shunt reactors
- Active filter: Static Var Compensation, STATCOM

PROCUREMENT / HARDWARE (3/3)



Rectifiers

- Rectifier transformers (6-36 kV)
- AC/DC Rectifier (<1500V): Diode, Thyristor, IGBT, SiC

MV Products

- Primary Distribution
- Secondary Distribution
- AIS / GIS
- Busbar
- Breakers
- Etc.

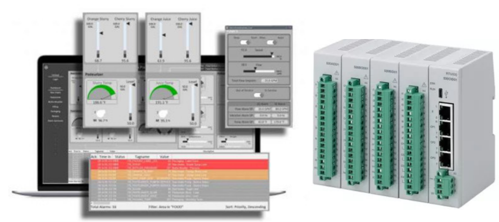
Low-voltage products

- Busbar
- Breakers
- Meters
- Etc.

Protection & Control

- Protection Relay
- Sensors
- Arc Protection
- Automation System

Digital solutions

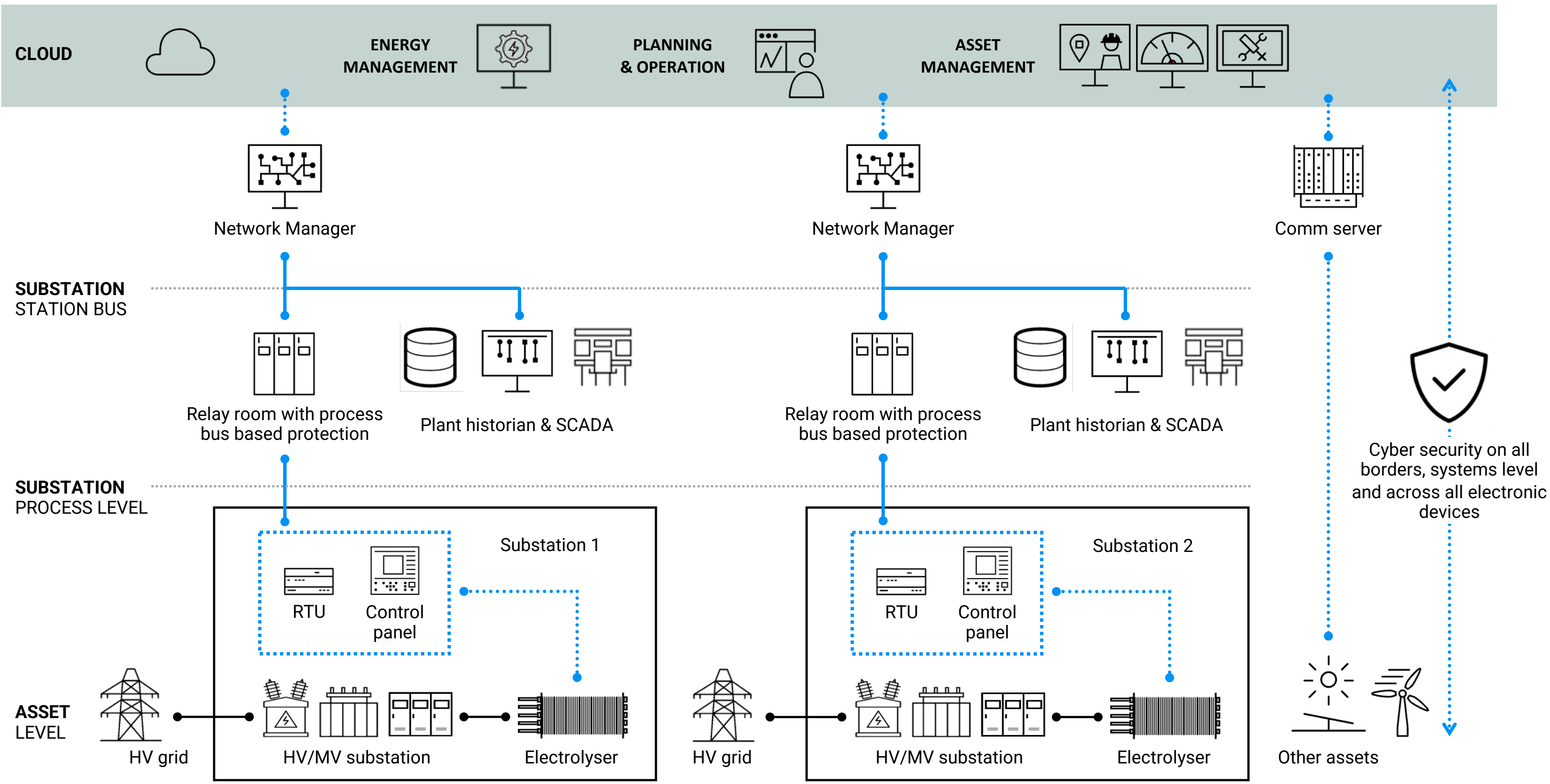


- RTU & control panels
- Historian / SCADA
- Network & servers
- Asset management software, Energy management system …

Nota : *) See section « Automation »

PROCUREMENT / DIGITAL SOLUTIONS

High-level control of the entire H2 plant (electrical substation + stack + BoP)



INSTALLATION / TECHNICAL INTEGRATION

Loose products & bundles


+


Ex: MV distribution panel + maintenance bundle

- **Loose product** : single product and/or services sales
- **Product & service bundles** : simple group of products or services on one purchase order without additional project management, integration engineering or technical or commercial cross-coordination
- Technical integration is carried out either internally by the customer or by a third-party electrical contractor

Packages & systems


+

+


Ex: stepdown transformer + switchgear engineered package

- **Electrical package** : seamless integration of multiple product elements (interface engineering & logistical coordination)
- **System** : Engineered sub-plant or plant system with design or performance responsibility
- Undertaking project execution under a single commercial agreement, with a common project management umbrella providing coordination and interface engineering between the products, helps accelerate the project energization time and reduces total project cost

Services & full turnkey solutions


OR


Ex: installation & commissioning services or turnkey substation

- **Turnkey solution** : solution that is designed, developed, and delivered by a single provider, offering a complete and ready-to-use product or service to the end-user.
- Single point of contact to execute the project package and coordinate service and commissioning
- Transfer of risk from client to contractor for coordinating design interface of all elements in the package to form a single product solution

MAINTENANCE

"Maximize availability, optimize overall performance and prevent costly failures"

Reliability centered maintenance strategy (RCM): Reliability centered maintenance strategy is based on optimizing maintenance investment by limiting the execution of unnecessary tasks while focusing on substation components representing higher risk. This evaluation includes Failure Modes and Effect Analysis (FMEA) to determine the best maintenance strategy to maintain reliability.

Main Maintenance strategies

Substation maintenance is a process of periodic, planned inspection of and, if necessary, repair, and replacement of switchgears, buildings, and ancillary equipments. It consists of physical inspection of equipments, cleaning, lubrication, readjustment of connections, testing, modifications, adjustments, and replacement of parts, in order to keep all the electrical substation in good working order.

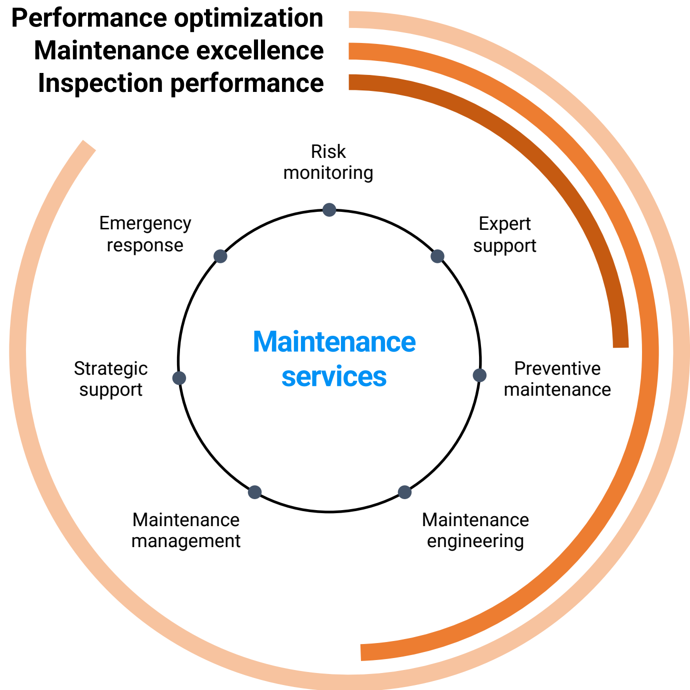
Four main maintenance strategies are possible for prolonging the service life of valuable assets :

Time based maintenance strategy (TBM): The maintenance schedule is periodic according to the manufacturer's generic maintenance schedule, including include provision of spare parts, consumables and replacements during service life.

Condition based maintenance strategy (CBM): The maintenance schedule is designed according to the condition of the equipment (requires a detailed condition evaluation of the installed equipment).

Importance based maintenance strategy (IBM): The maintenance schedule is based on the importance of the equipment (importance is calculated based on the failure mode and effects analysis) with a detailed risk modelling analysis carried out beforehand.

Overview of maintenance services



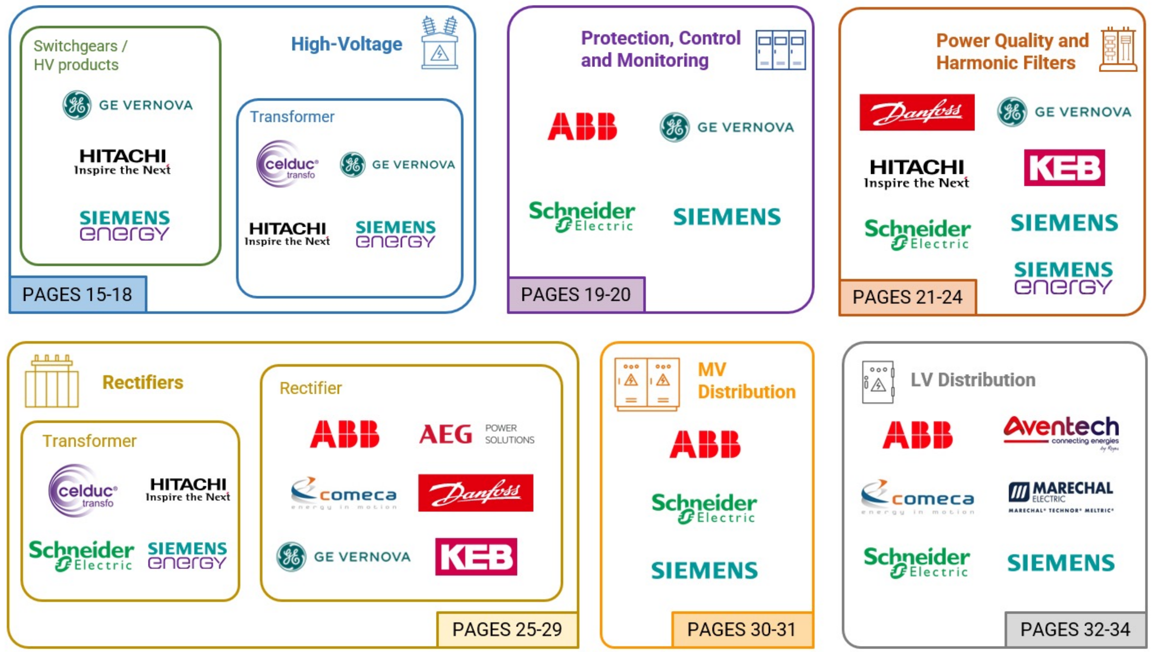
Credit : Hitachi Energy, ABB

Companies providing Power Supply Solutions

This white paper presents the challenges and constraints for electrolysis power supply.

→ Discover the solutions offered by **GIMELEC members** to meet these needs: 13 of our experts present their offer, from **loose products and bundles**, **packages and systems**, to **services and full turnkey solutions**.

→ This directory also allows you to find out more about the GIMELEC companies active in power supply.
Click here to access the GIMELEC directory



→ For solution providers covering the entire hydrogen value chain (production - storage - transport - distribution - applications), find the Panorama of H_2 Solutions proposed by France Hydrogène online.

→ On the Vig'hy hydrogen observatory, you will also find the online directory of **France Hydrogène members**: 450 French hydrogen industry players covering the entire value chain: major industrial groups, SMEs, start-ups, laboratories and research centres, associations, competitiveness clusters and local authorities.