Topologies Comparison for Wind Turbine Electrolyser Power Supply

CPE 2023 – July 2023

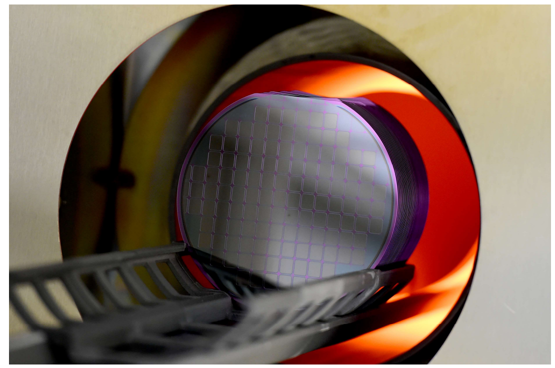
Dr Fisal Al Kayal, Dynex Semiconductor Ltd

Agenda

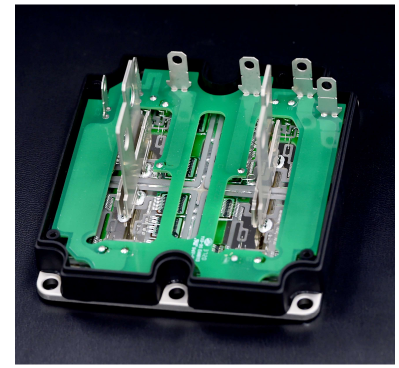
- Introduction to Dynex Semiconductor
- Why Hydrogen
- Power supply topologies comparison
- Validation
- Conclusion

INTRODUCTION TO DYNEX

- Over 60 years' experience in the design and build of Power Semiconductors and Heatsink Assemblies
- Manufacture IGBTs, Diodes, Thyristors, GTOs and Heatsink Assemblies
- Based in Lincoln, 2x 6" Silicon Wafer manufacturing lines with a combined capacity of 80,000 wafers per annum
- Bespoke Assemblies designed, manufactured and tested in-house



Semiconductor Manufacturing



Packaging Design

Converter Design and Assembly

High Power Test

Product technologies overview

IGBT

High Voltage IGBT

(3.3kV to 6.5kV)

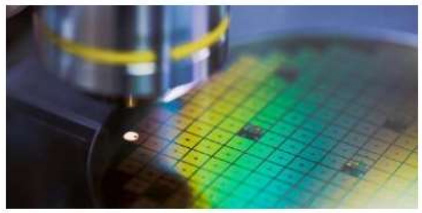
Low/Medium Voltage IGBT

(750V to 1.7kV)

Automotive

Custom Modules

Silicon Carbide



UNDER DEVELOPMENT

SiC Diode

SiC MOSFET

SiC Module

Bipolar

HVDC Thyristors

Phase Control

Thyristor

Rectifier Diode

Fast Thyristor

Fast Diode

Bidirectional thyristor

GTO

IGCT

Power Assemblies

Power stack design and build

Air and liquid cooling design

High voltage design

Gate driver design

Contract Services

Traction Converter, Upgrade & Overhaul

Complete power converter with control system

Product technologies overview

Traction

Railway traction

Marine traction

Tram traction

Energy

Power grid quality

HVDC

Solar

Wind

Industrial

High power motor drive

AC inverters

High power converter

Electric Vehicle

EV Charger Infrastructure

Electric Racing Cars

High performance road vehicles

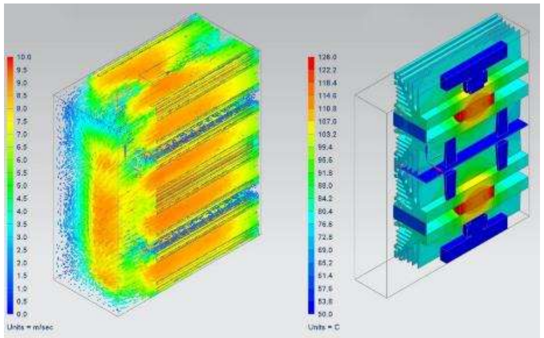
Agricultural Vehicles

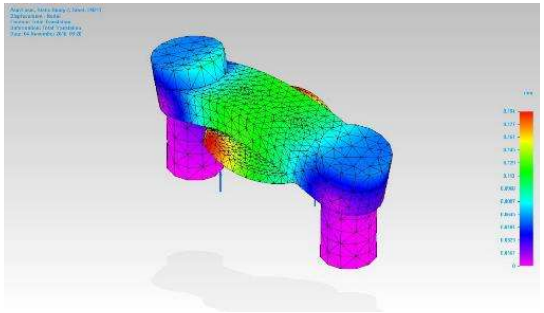
Industrial vehicles

DESIGN CAPABILITIES

Applications Support, Clamp provision, System Design and Construction

- Team of experienced experts in Device Physics, Electrical, Electronic and Mechanical Engineering
- Tailored design to meet specifications
- In-depth knowledge of wear out mechanisms to design Assemblies for a range of applications
- Ability to tailor device performance and packaging to suit needs of the application
- Electrical circuit, mechanical stress and CFD simulation expertise

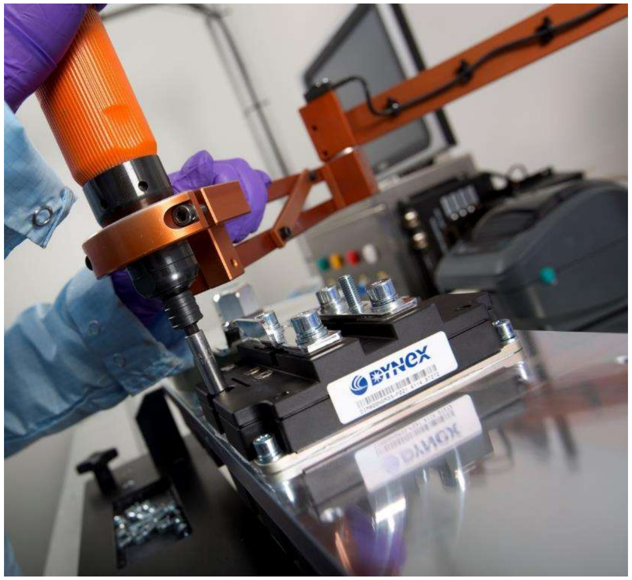




MANUFACTURING CAPABILITIES

Assembly, Test and Manufacturing Engineering

- Experienced team trained in high voltage wiring, crimping, clamping and other manufacturing processes
- Full traceability of materials and operatives
- In house machining capability
- In house test facility to test full range of product
- Process traceability with barcode scanning of sub-components and data verification
- ESD clean room assembly facility and environment with Semi-Automated mount down and assembly equipment
- Adaptable to work on lower quantity product as well as larger production runs



On-site Power Testing Facility

Testing up to 100kV and 4kA

Liquid flow rates up to 120 L/min

Assemblies up to 2 tonnes in weight

The Power Assemblies group can provide on-site power testing. Assembled products can be verified for standard end of line testing for example, isolation tests, partial discharge measurements and switching tests. The team can provide specialised tests on custom assemblies, such as high energy crowbars and controlled 3 phase rectifiers, testing up to 100kV and 4kA.

As part of the test facility we are able to perform pressure and thermal heat run tests using our localised liquid cooling plant for assemblies that use liquid flow rates up to 120 L/min.

POWER FACTOR CORRECTION

TCR & TSC outlines for Power Conditioning

- Water cooled and force air outlines for Power Factor Correction
- Collaborative design effort with end customer to provide a tailored semiconductor to suit the application
- Proven designs have been in operation for >80,000 hours
- Designs up to 400Mvar/37kV TCR down to 5Mvar/1.4kV TSC
- Water cooled snubber
- Incorporation of customers free issue components

EXCITATION & ELECTROLYSIS SYSTEMS

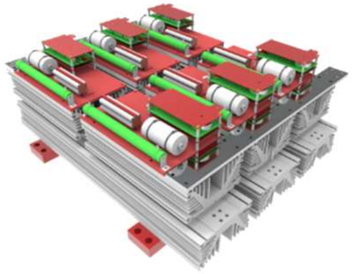
High Power rectifiers for Hydro dam Excitation and Hydrogen Electrolysis

- High power rectifier systems for demanding applications
- Tailored design with redundancy and maintainability built in
- Assembly design to withstand corrosive environment
- Designed with complimentary crowbars and anti-spike filters
- Proven design with >60,000 operation in high humidity environment

STANDARD POWER ASSEMBLIES

Clamps, Rectifiers, AC Switches, Crowbars

- A selection of standardised outlines in proven natural convection, forced air and water cooled designs
- A range of standard clamps matched to our devices with options on mounting and isolation
- Options for Gate Drives for high isolation
- Snubbers designed to suit application
- Options for resistance to corrosive environments



TRACTION CONVERTER UPGRADE AND OVERHAUL

Railway Converter Maintenance, Repair, Obsolescence Management & Repowering

- Converter mid-life upgrade/overhaul
- Reliability improvements
- Spares and Repairs
- Propulsion modernisation and upgrade
- Obsolescence management
- Support for track side applications such as rectification circuits

LNER LONDON NORTH EASTERN RAILWAY

GBRf

porterbrook

DB Cargo

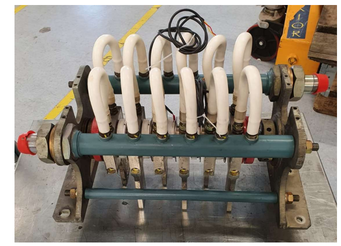
ALSTOM

Wabtec CORPORATION

UNDERGROUND

SIEMENS

Dynex designed converter for Class 73 re-traction project (IGBT)



Class 91 Heatsink refurbishment (GTO and Diode)

Class 92 Heatsink refurbishment (GTO and Diode)

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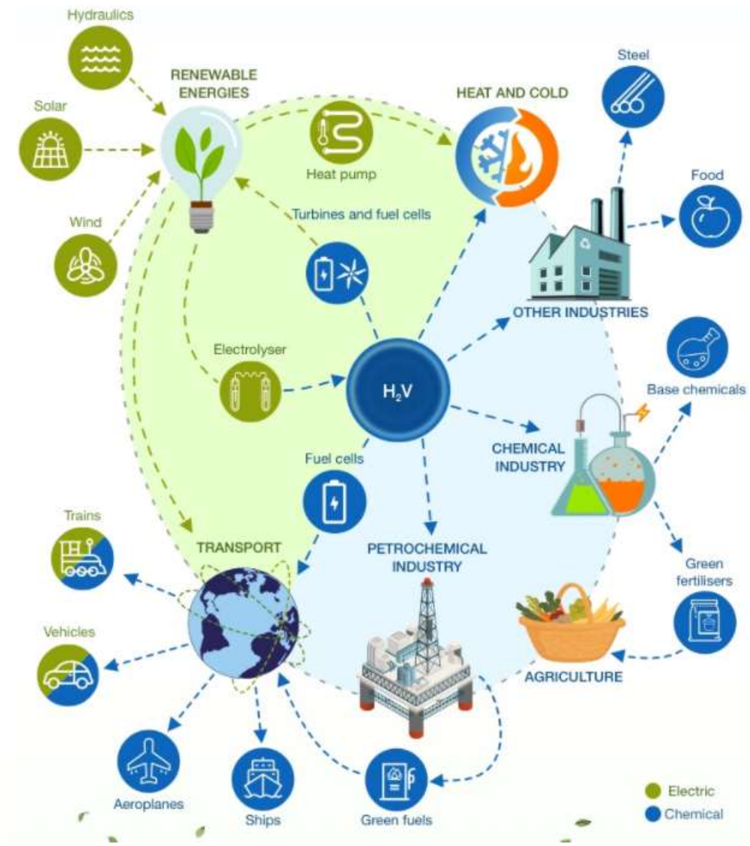
WHY HYDROGEN?

Hydrogen is the most abundant chemical element estimated to contribute 75% of the mass of the universe

Why is hydrogen important?
Hydrogen is a chemical that can be “burnt” to produce energy
When Hydrogen is “burnt” the ONLY waste product is water vapour & oxygen (NO CO_2)

Think of Hydrogen as an alternative storage medium (like a battery)

What can Hydrogen be used for?
- Powering vehicles (hydrogen fuel cells
- Energy generation(turbine)
- Energy storage

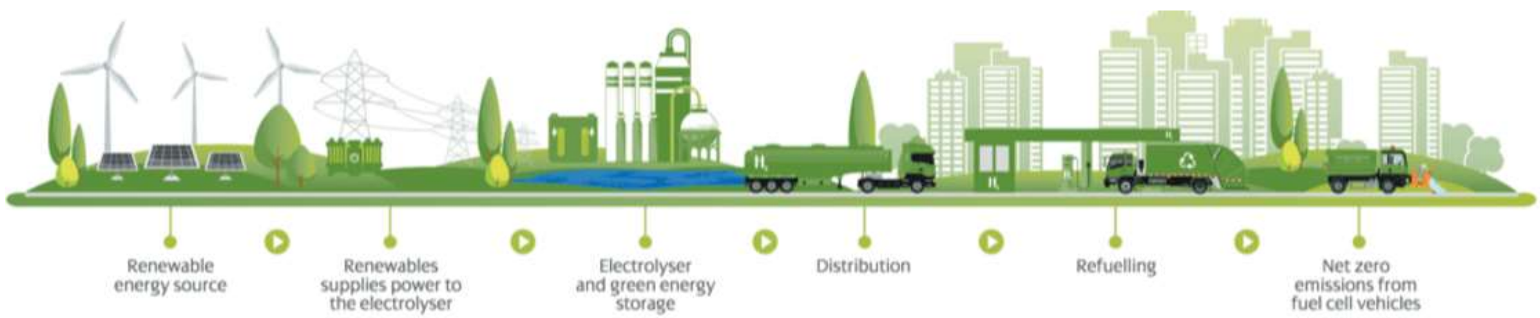


TYPE OF HYDROGEN?

There are more than one type of Hydrogen based on the technology used to produce it

Green Hydrogen – Made using renewable energy sources (solar/wind etc)
Blue Hydrogen – Produced from natural gas by steam reforming. Low carbon hydrogen
Grey Hydrogen – Produced from natural gas, methane etc. Most common form a the moment
Black/Brown hydrogen – Produced from black coal
Pink hydrogen – Produced from nuclear energy sources
Yellow hydrogen – Produced solely from solar power
White hydrogen – Natural hydrogen sourced by “fracking”

OUR FOCUS WILL BE GREEN & YELLOW HYDROGEN EQUIPMENT

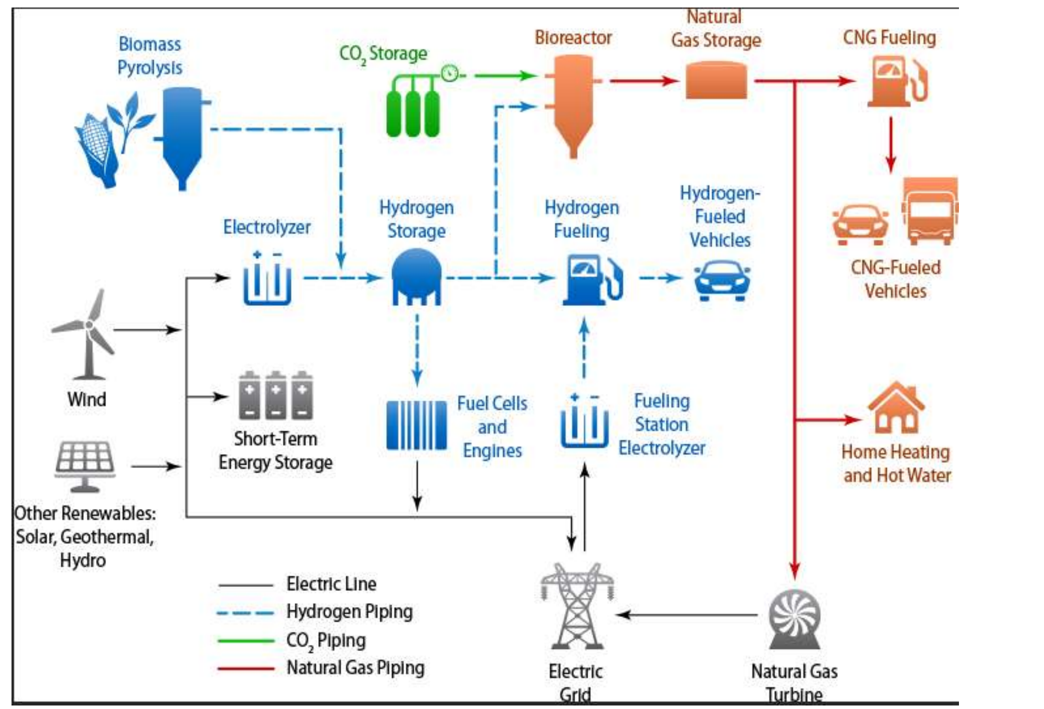


WHAT DOES HYDROGEN ELECTROLYSER DO?

A hydrogen electrolyser is the apparatus that produces hydrogen through a chemical process (electrolysis)
If using renewable energy sources then green or yellow hydrogen can be produced without emitting ANY carbon dioxide.

Hydrogen produced can then be stored until required to:-

- Power vehicles
- Produce electricity
- Be easily transported to another location



TYPE OF HYDROGEN ELECTROLYSER

There are different types of electrolysers that can vary in size and function

Alkaline Electrolyser

- Oldest method.
- Can be bulky
- Only produce medium purity hydrogen

Proton Exchange Membrane (PEM)

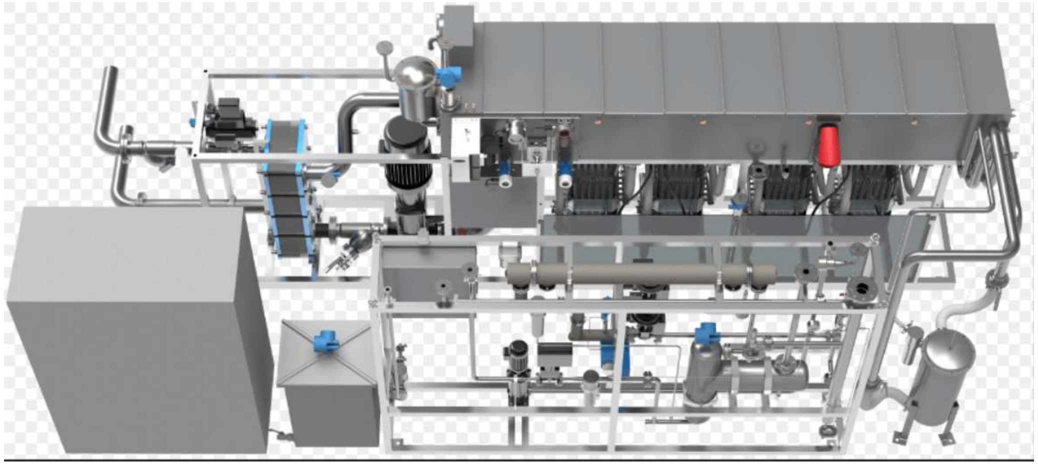
- Most popular type
- High purity hydrogen
- Are expensive as use precious metals

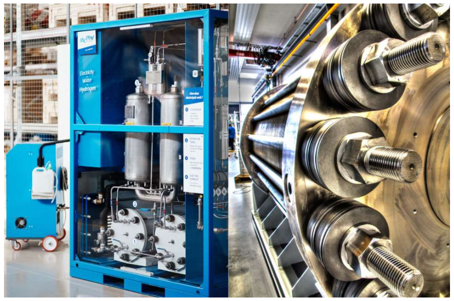
Solid Oxide Electrolyser (SOEM)

- Newer technology
    - Have potential to be most efficient

Photoelectrolysis

- Uses only sunlight
    - Undeveloped. Requires undeveloped semicondctors (custom?)



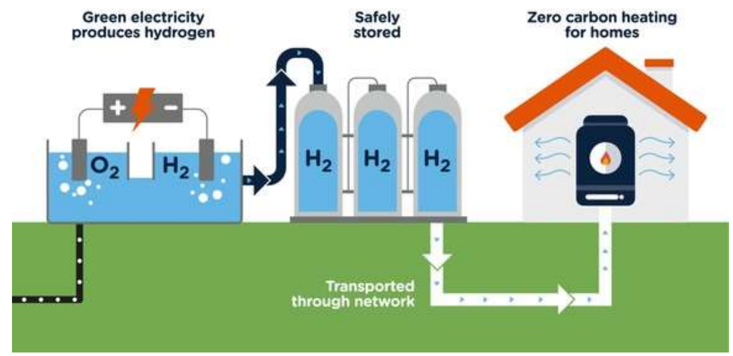


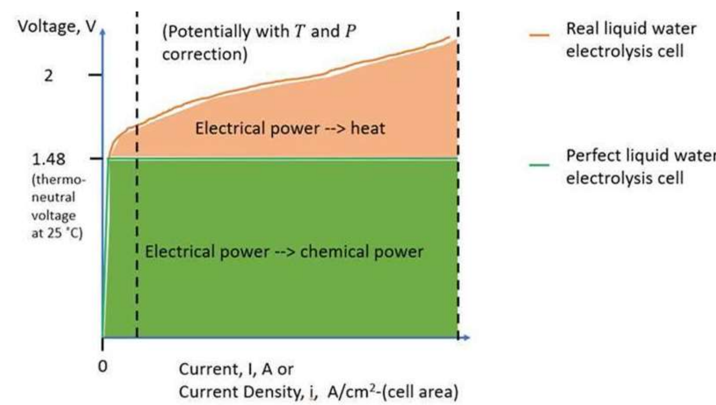
ELECTRICAL SUPPLY FOR ELECTROLYSIS

Electrolysis is achieved by passing a DC current through a membrane

The cells work like a battery charger, operating in constant current with the voltage changing based on the temperature of the cell

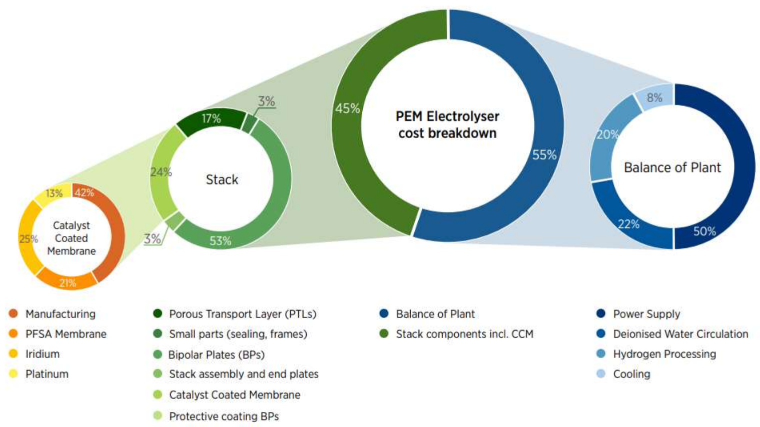
Optimal operation at the knee point of current, additional power applied gives lower efficiency of H2 generation





GREEN HYDROGEN CHALLENGE

- Earth shot prise to achieve Green Hydrogen cost of $1 per kg in 1 decade (“1 1 1”)
- Currently $8 per kg
- Cost breakdown shows power supply contributes 27% of the overall cost of a PEM electrolyser (most common type)
- Electrolysis companies commonly concentrating on the membrane technology, rather than the power supply and use COTS part – need support to move into 1MW+



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HYDROGEN POWER SUPPLY SPEC

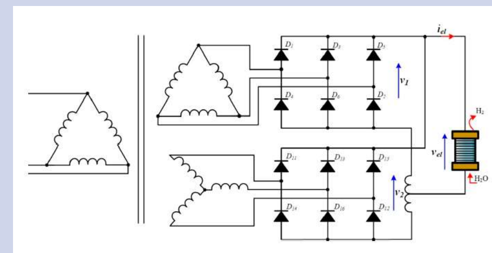
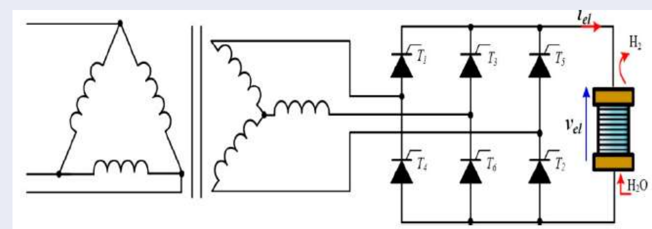
Power supplies state of the art*

Several types of AC to DC converter could be used. Question of choosing the right converter for a given electrolyser:

1. Controlled output current or controlled output voltage
2. Interaction between the converter and the power source (Power Factor, injected harmonics in the power source,…)
3. Efficiency
4. Reliability to ensure long lifetime and minimize failures
5. Output current ripple (small or big or controlled ?)
6. Cost

HYDROGEN POWER SUPPLY SPEC

Power supplies state of the art*

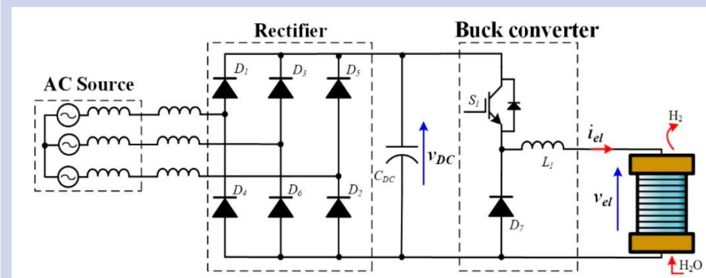
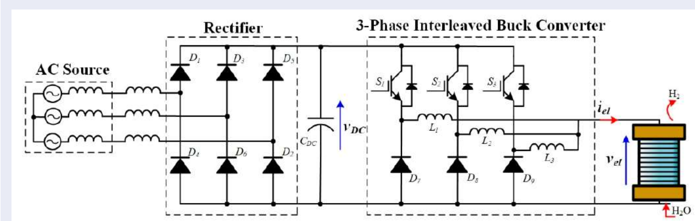
Topology	Advantages	Drawbacks	
Uncontrolled 3phase rectifier (6-pulse or 12-pulse)	Low cost High reliability High efficiency	Fixed Vout Poor PF High current ripple High current harmonics	
Controlled rectifier (thyristor based rectifier)	<u>Controlled Vout</u> Low cost High reliability High efficiency	Poor PF High current ripple High current harmonics	

*** AC-DC Converters for Electrolyzer Applications: State of the Art and Future Challenges**

Burin Yodwong 1,2 , Damien Guilbert 1, Matheepot Phattanasak

HYDROGEN POWER SUPPLY SPEC

Power supplies state of the art*

Topology	Advantages	Drawbacks	
Diode rectifier + Buck or Boost converter	Controlled Vout Acceptable current ripple Acceptable reliability Acceptable efficiency Fast current dynamic response	Poor PF cost High current harmonics	
Diode rectifier + interleaved Buck or Boost converter	Controlled Vout Smaller current ripple Acceptable reliability Higher efficiency Fast current dynamic response Availability	Poor PF Higher cost High current harmonics	

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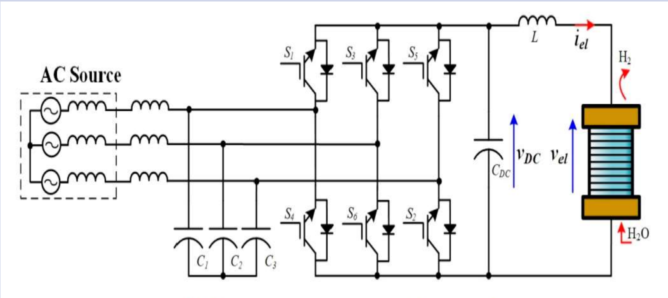
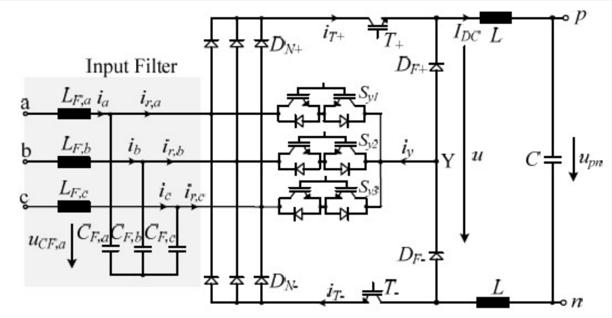
HYDROGEN POWER SUPPLY SPEC

Power supplies state of the art*

Topology	Advantages	Drawbacks	
PWM current source rectifier	Controlled Iout Excellent PF Smaller current ripple Efficiency Fast current dynamic response	Cost Complicated control Over-voltage across IGBTs	 PWM current-source rectifiers for electrolyzer applications.
Swiss rectifier (buck type PFC rectifier)	Controlled Iout Excellent PF Smaller current ripple Higher Efficiency Fast current dynamic response	Cost	

*** AC-DC Converters for Electrolyzer Applications: State of the Art and Future Challenges**

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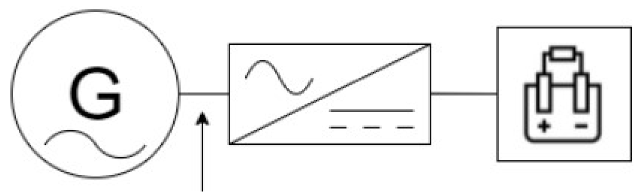
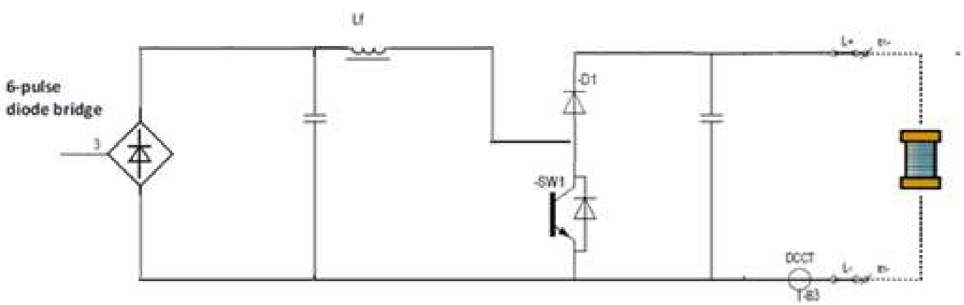
HYDROGEN POWER SUPPLY SPEC

Case of study

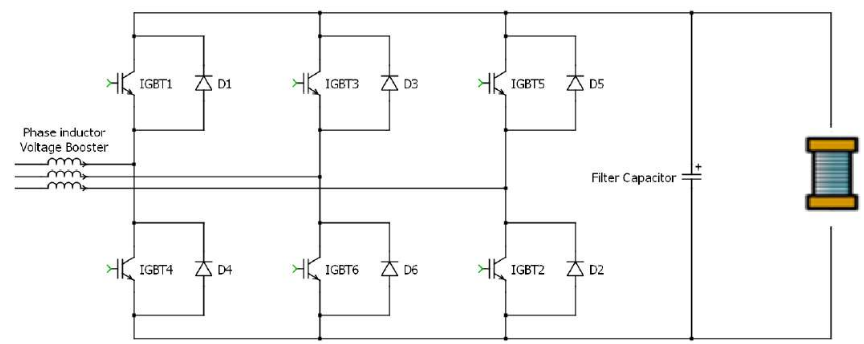
- Output Power : 4MW
- Input voltage: 415Vrms/50Hz
- DC Output voltage: **800Vdc**
- Current ripple : from 1% to 5%
- Power factor: close to unity



2 different topologies will be analyzed:

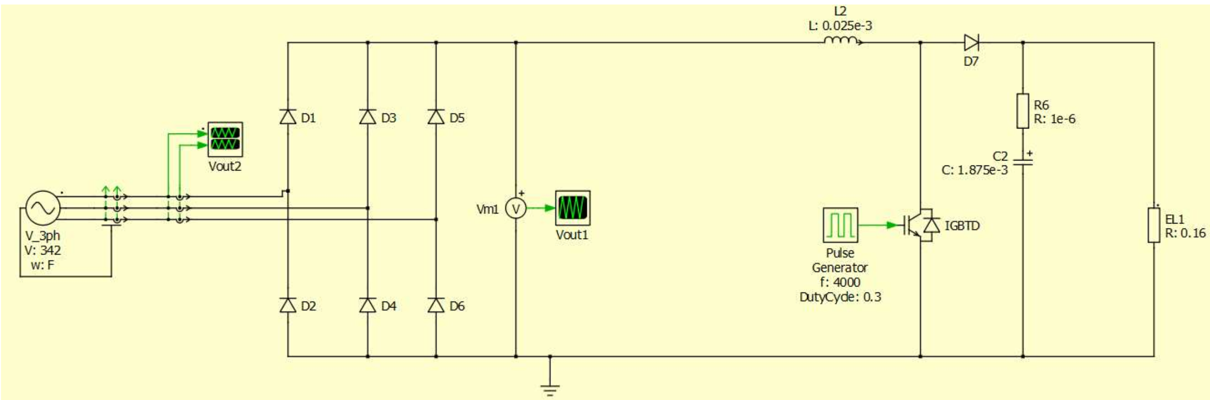


Diode rectifier + Boost converter



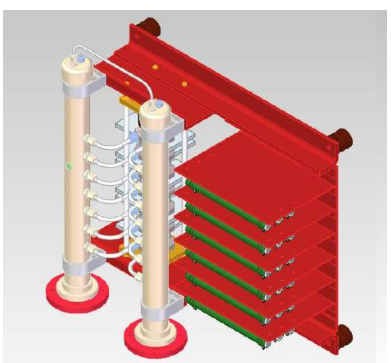
Active front end boost converter

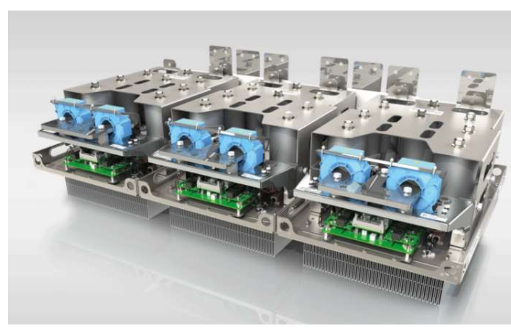
DIODE RECTIFIER + BOOST CONVERTER



HV diode + snubber

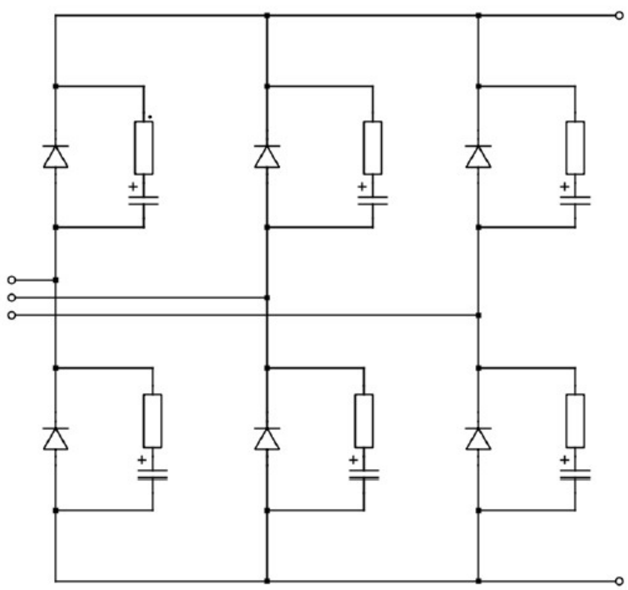
Fsw, L and C will determine output Voltage and current ripple

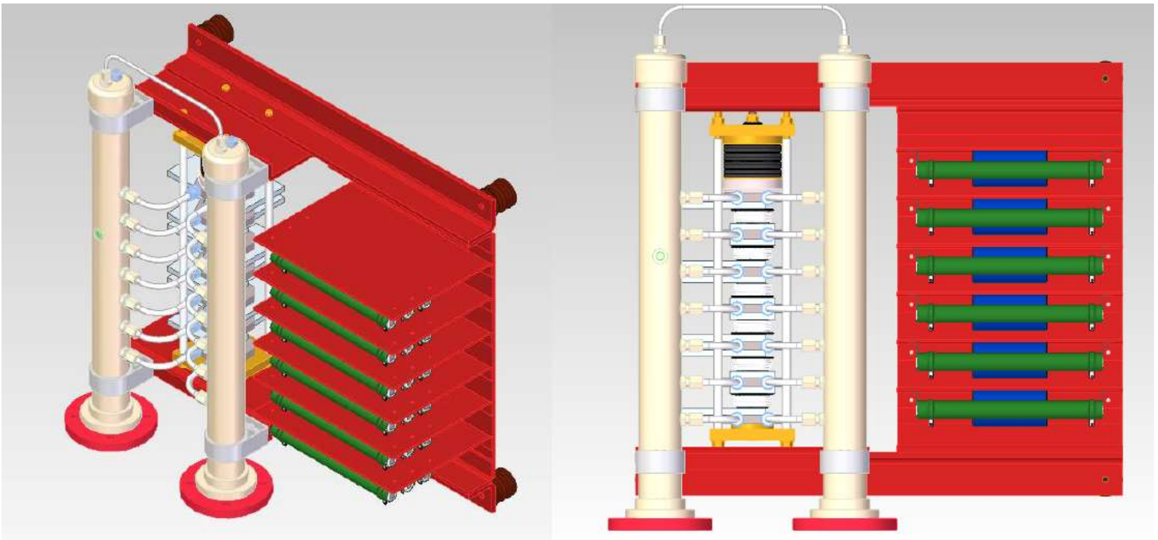




DIODE RECTIFIER + BOOST CONVERTER

Rectifier design





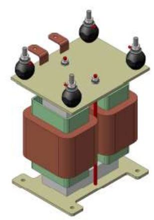
Rectifier layout

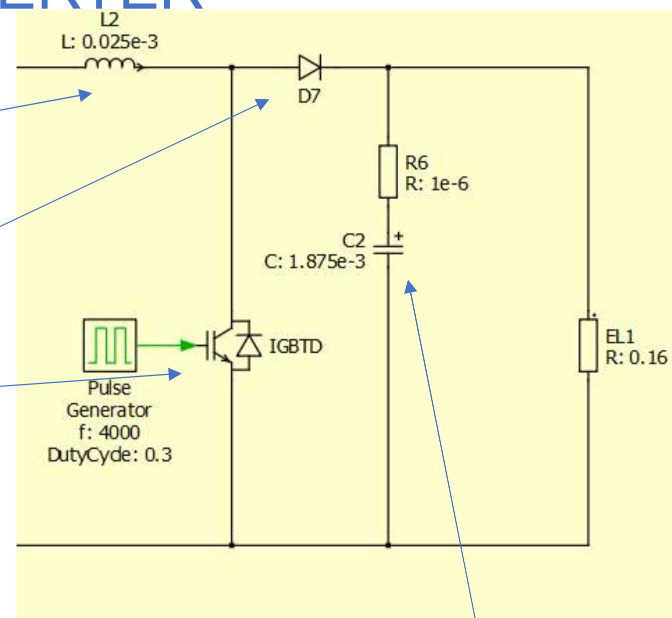
Total losses = 2760W x 6 thyristors + 1500W snubber = **18kW**

Length	1000mm
Width	500mm
Height	1000mm

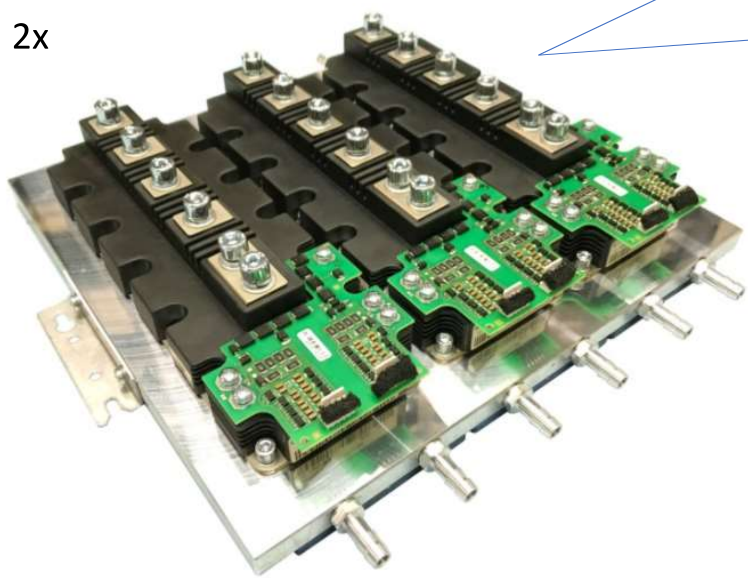
DIODE RECTIFIER + BOOST CONVERTER

Boost design





2x

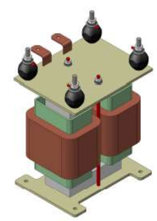


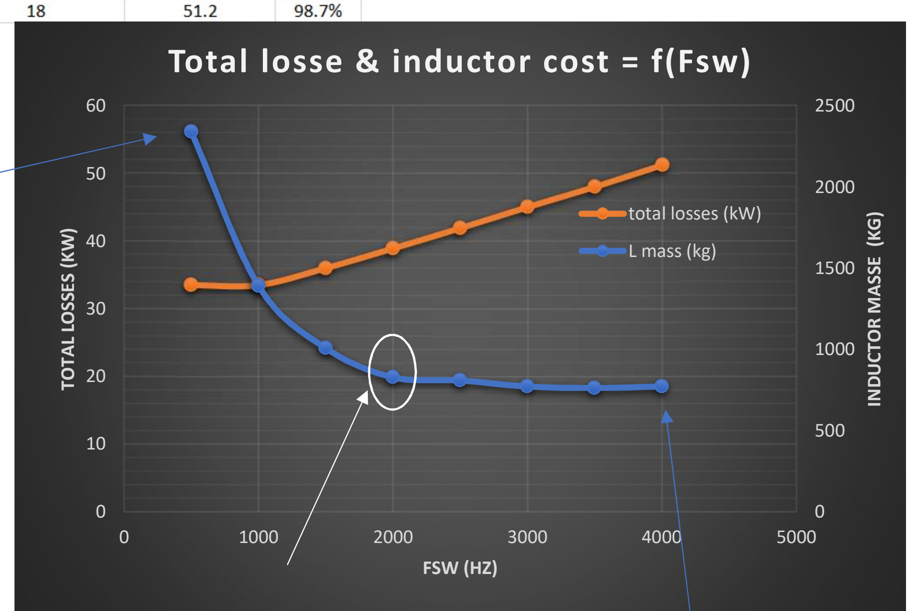
DIODE RECTIFIER + BOOST CONVERTER

Boost optimization

Fsw (Hz)	L (mH)	rms	pk	C (mF)	I_C (Arms)	Iout ripple pk-pk (%)	L mass (kg)	SC Losses (kW)	L losses (kW)	Rectifier Losses (kW)	total losses (kW)	eff
500	0.2	7080	7910	15	3275	25	2340	5	10.5	18	33.5	99.2%
1000	0.1	7080	7910	7.5	3275	25	1391	8.2	7.3	18	33.5	99.2%
1500	0.065	7080	7910	5	3275	25	1008	11.5	6.5	18	36	99.1%
2000	0.05	7080	7910	3.75	3275	25	828	14.5	6.4	18	38.9	99.0%
2500	0.04	7080	7910	3	3275	25	809	17.7	6.2	18	41.9	99.0%
3000	0.033	7080	7910	2.5	3275	25	771	21	6	18	45	98.9%
3500	0.028	7080	7910	2.15	3275	25	762	24.1	5.9	18	48	98.8%
4000	0.025	7080	7910	1.875	3275	25	771	27.3	5.9	18	51.2	98.7%

There is always an optimal switching frequency for better efficiency and cost



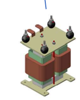


DC FILTERING

FFLI 800V to 1400Vdc

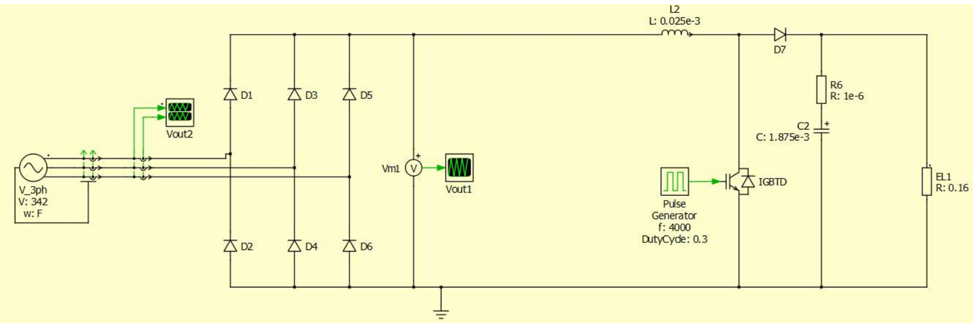
Need of **33** capacitors 340mm * 116mm

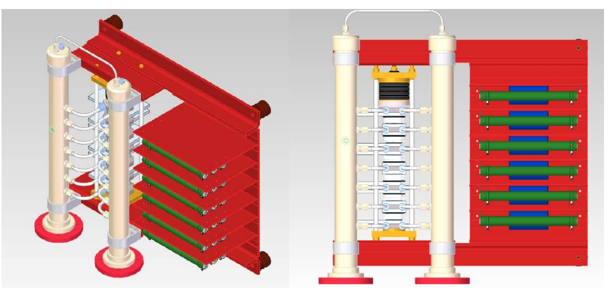
@4MW, 2000Hz looks best compromise (efficiency, weight and cost)



DIODE RECTIFIER + BOOST CONVERTER

Design conclusion



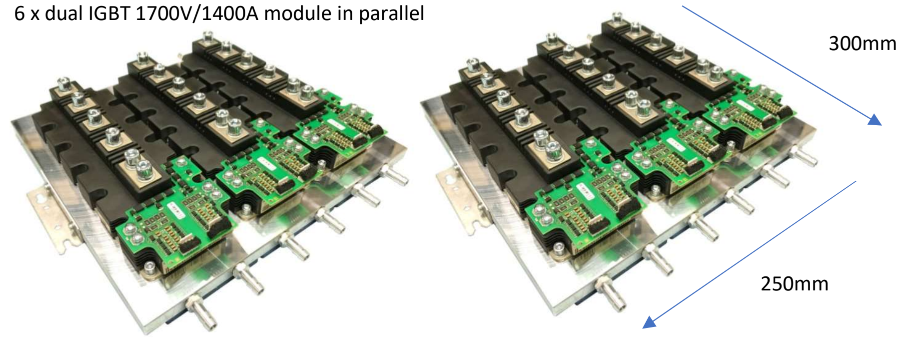


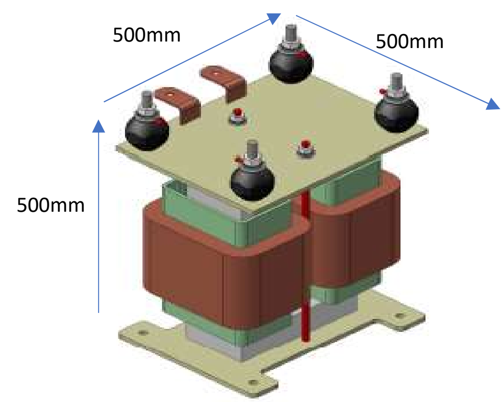
Length	1000mm
Width	500mm
Height	1000mm

18kW rectifier loss

Total losses: 40kW

6 x dual IGBT 1700V/1400A module in parallel





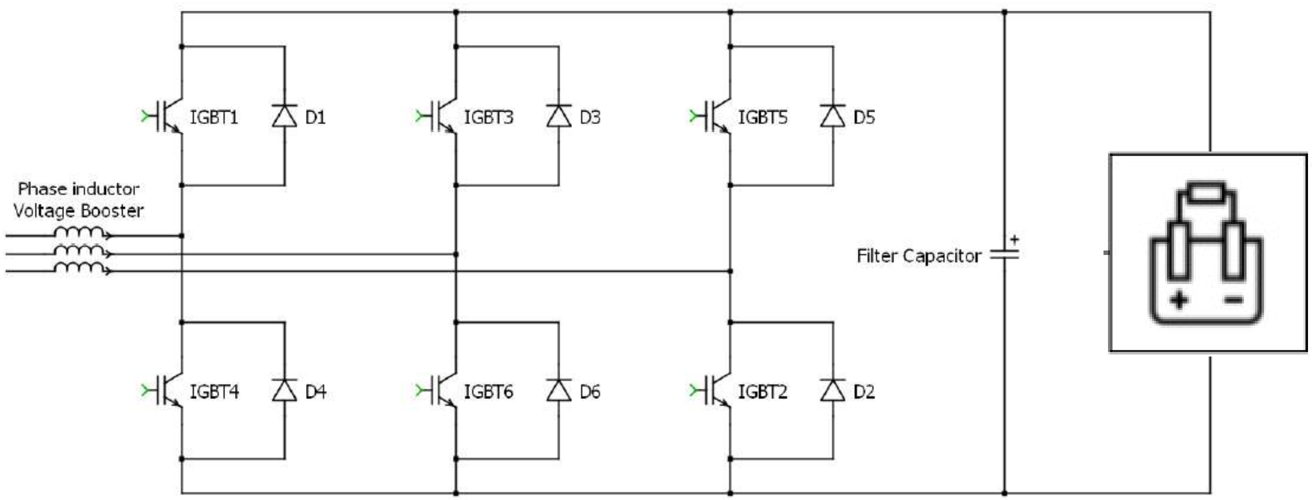
33 x D:116, H:340mm
4.5kg each

830kg

21kW Boost loss

ACTIVE FRONT END CONVERTER

Electrical schematic



3 phase inductor to boost

Bi- directional rectifier/inverter

ACTIVE FRONT END CONVERTER

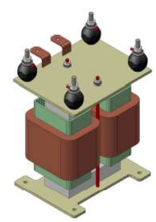
Design optimization

Fsw (Hz)	L (mH)	IL (Arms)	IL (Apk)	C (mF)	I_C (Arms)	Iout ripple pk-pk (%)	L mass (kg)	SC Losses (kW)	L losses (kW)	total losses (kW)	eff
500	0.06	5600	8550	15	3330	25	2054	11.7	11.4	23.1	99.4%
1000	0.055	5600	8550	7	3330	25	1911	18.3	10.1	28.4	99.3%
1500	0.05	5600	8550		3330	25	1778	25	9.45	34.45	99.1%
2000	0.045	5600	8550		3330	25	1645	31.6	8.9	40.5	99.0%
2500	0.04	5600	8550		3330	25	1508	38.8	8.4	47.2	98.8%
3000	0.035	5600	8550		3330	25	1361	45	7.9	52.9	98.7%
3500	0.03	5600	8550		3330	25	1212	51.6	7	58.6	98.5%
4000	0.025	5600	8550		3330	25	1057	58.3	6.4	64.7	98.4%

There is always an optimal switching frequency for better efficiency and cost

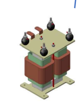
DC FILTERING

FFLI 800V to 1400Vdc



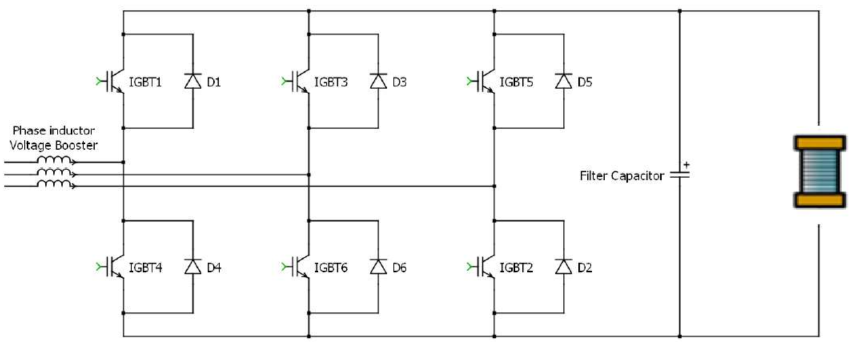
Need of **33** capacitors 340mm * 116mm

@4MW, 2200Hz looks best compromise (efficiency, weight and cost)

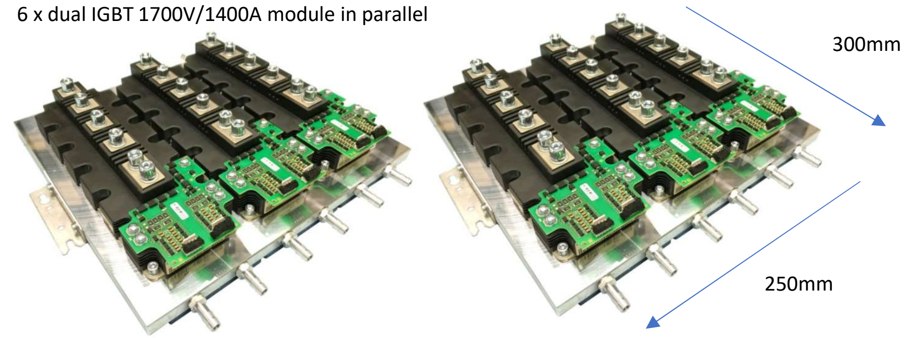


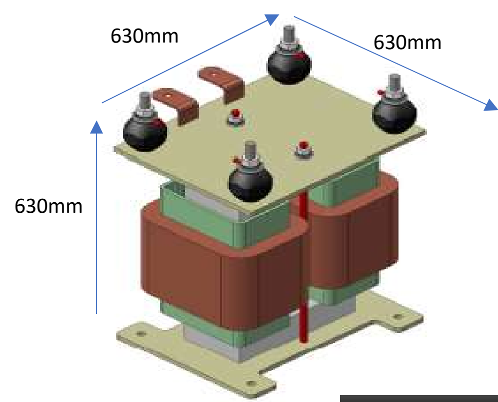
ACTIVE FRONT END CONVERTER

Design conclusion



6 x dual IGBT 1700V/1400A module in parallel





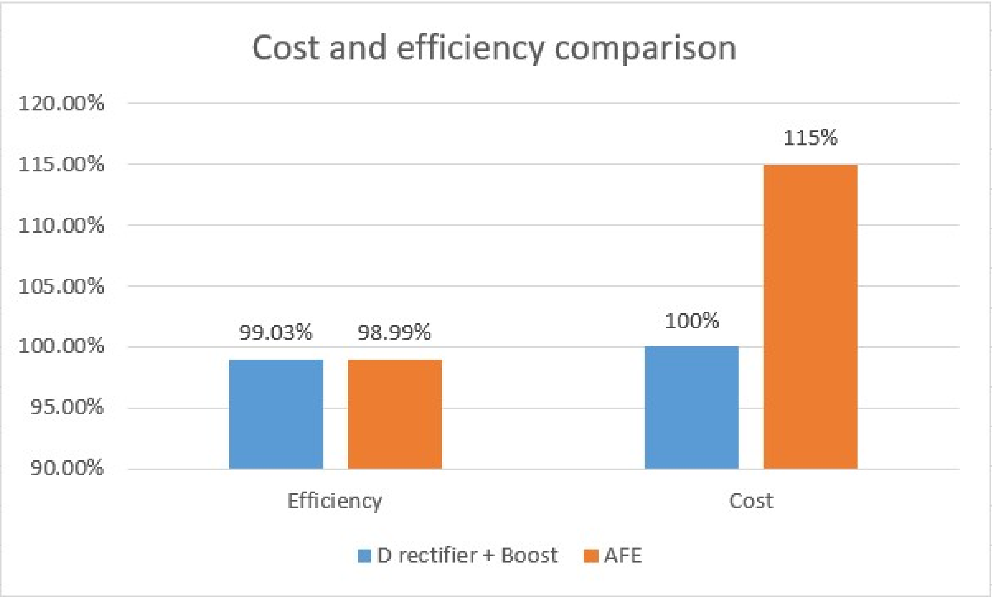
33 x D:116, H:340mm
4.5kg each

1645kg

Total losses: 40.5kW

ACTIVE FRONT END CONVERTER

Efficiency and Cost Comparison



Agenda

- Introduction to Dynex Semiconductor
- Why Hydrogen
- Power supply topologies comparison
- Validation
- Conclusion

Prototype testing

300kW AFE testing

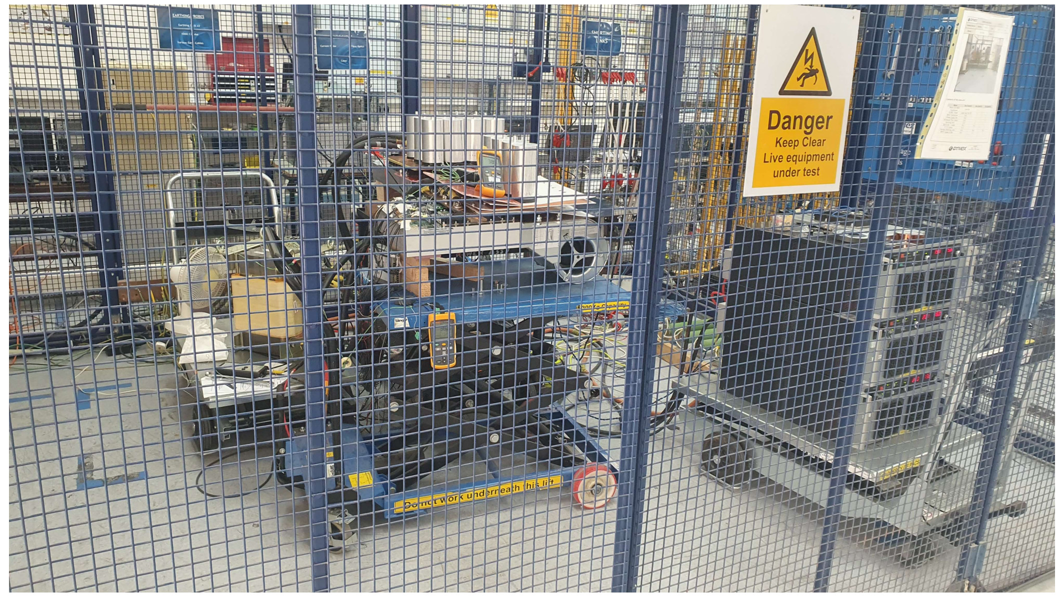
Functional test and heat run test @ 300kW
Vin = 415 Vrms
Vout = 800Vdc

↓

No source or load available @ this power rating for the time being

↓

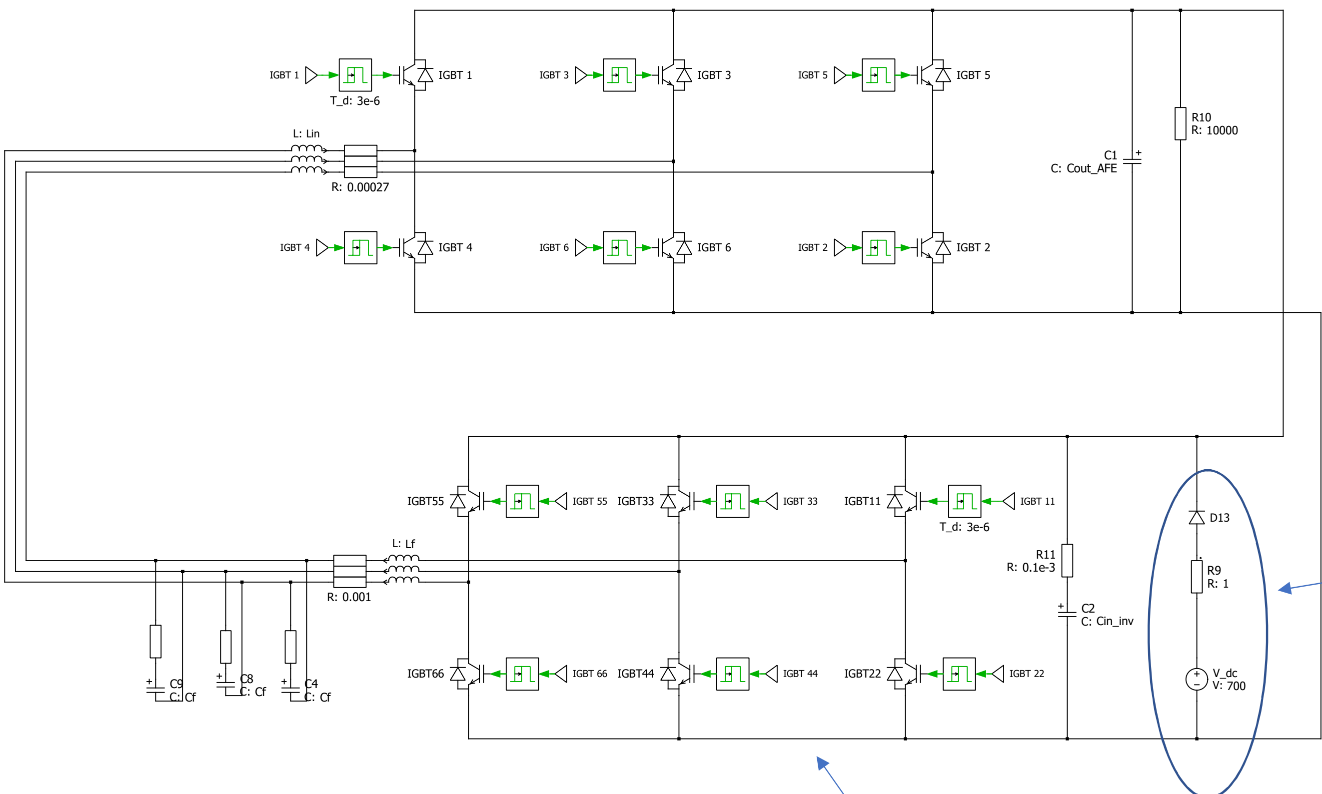
Back to Back testing



Prototype testing

300kW AFE testing

AFE



3 phase inverter

Test done @:

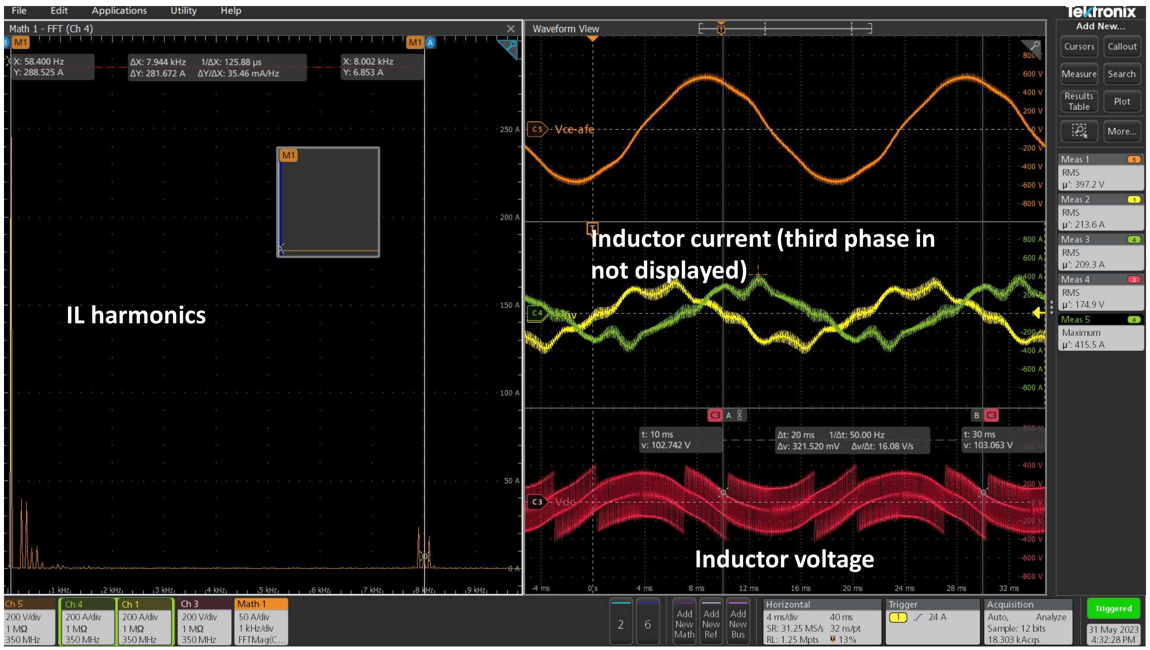
300kW circulated power

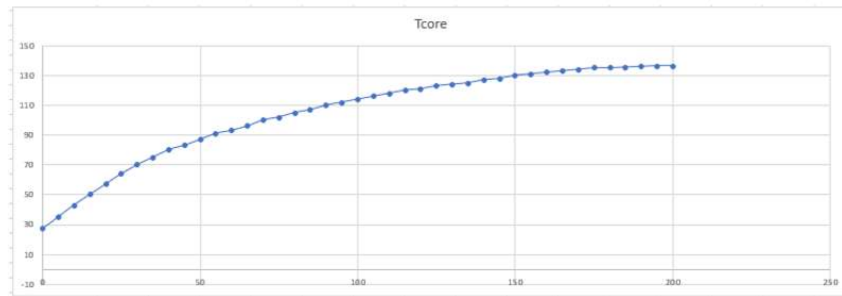
Consumed power= **15kW**

DC Voltage source to compensate losses

Prototype testing

300kW AFE testing



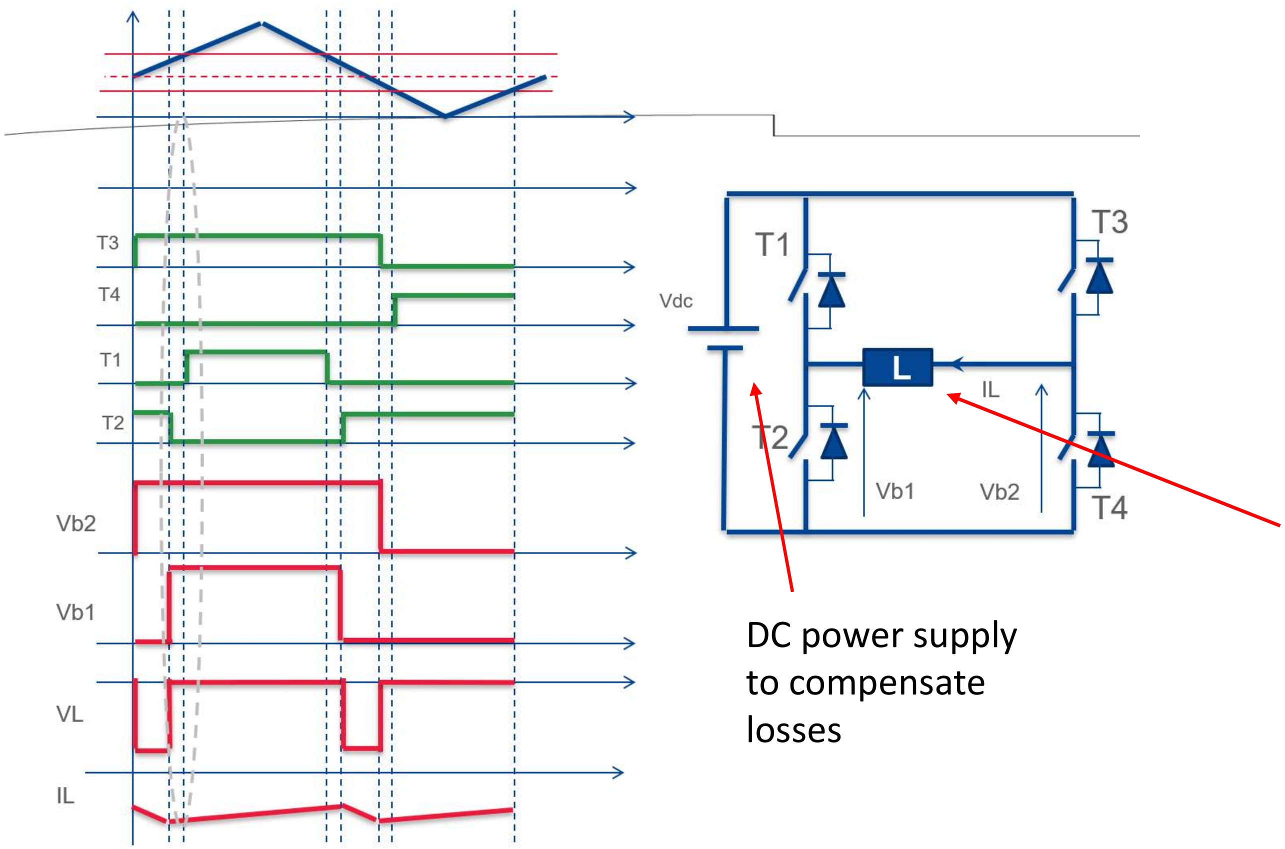


Time (min)

Prototype testing

300kW DC Back to Back testing

Using this B2B, the inductor current could be set to any value if the losses of semiconductor are acceptable



DC power supply to compensate losses

Device under test

Agenda

- Introduction to Dynex Semiconductor
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Conclusion

- Several power supply topologies has been compared for the Hydrogen power supply market
- Case study: detailed comparison between (D rectifier + Boost) and (AFE) has been done
- Testing using a Back to back converter to avoid using loads