The energy transition results in a power electronics dominated power system

LISTALKS on energy transition, Wednesday 23rd February 2022

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About Hitachi Energy

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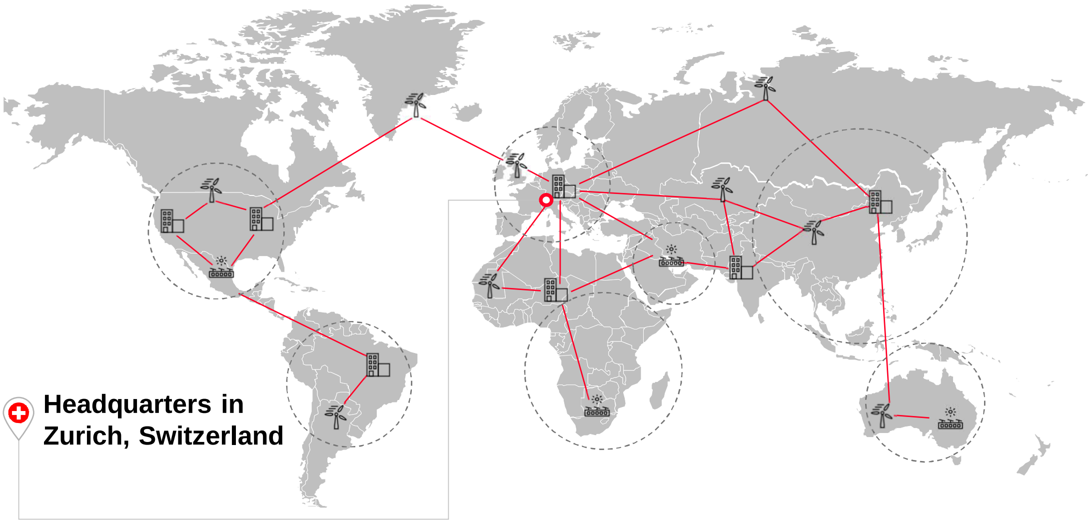


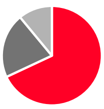
38,000 employees

90+ countries with 200 offices	**~250** years' heritage combined
5,500 sales employees & field engineers	**2,000** engineers & scientists in R&D

Four Business Units

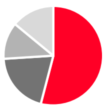
Grid Automation	High Voltage Products
Grid Integration	Transformers

Customers



- Transport & Infrastructure
- Industry
- Utilities

Offering



- Services
- Software & Automation
- Systems
- Products

Geographies

- Asia, Middle East & Africa
- Americas
- Europe

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Global technology and market leader

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Grid Automation

50% **of the top 250** global electric utilities supported by our leading portfolio

~$4 trillion mission-critical infrastructure assets managed with our software solutions

Grid Integration

Technology HVDC **leader** in power quality and grid connection solutions and services

Leader in HVDC* systems with **200 GW** installed

High Voltage Products

1 in every 4 **high-voltage switchgear** installed in the world

More than **1M** **circuit- breakers** installed in the world

Transformers

World's largest installed base of power, distribution, traction transformers

Technology leader in transformer applications for HVDC, renewables and digitalization

Services

Maintaining and modernizing the **world's largest** installed base

More than **200** **service centers and** **1,500** **field engineers** worldwide

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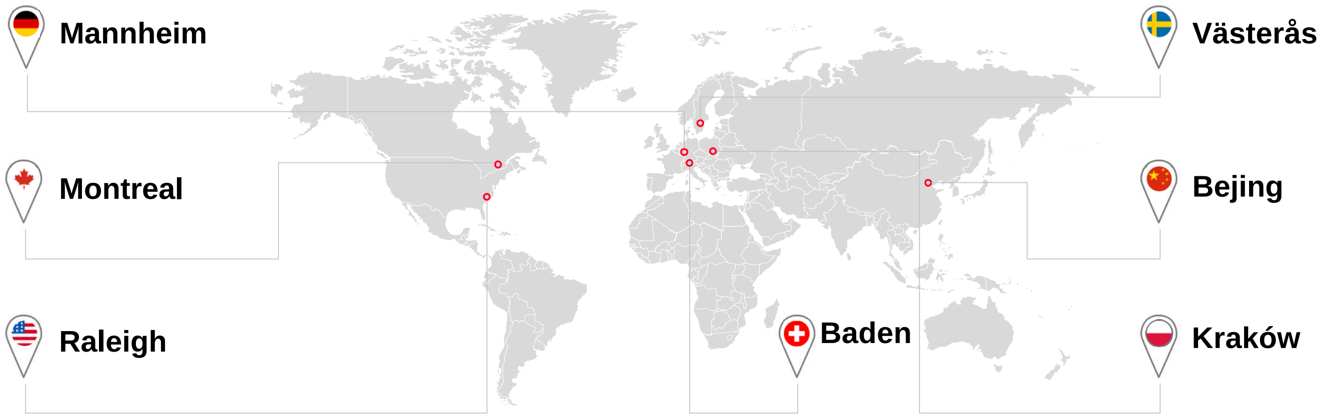
One global R&D organization

Our R&D team is present in **20+ countries** and we have Research Centers in **seven countries**



2000+ R&D experts	>60% work in software development	~200 researchers	>80% researchers have PhDs

Power system evolution and energy transition

Power system evolution with focus on power electronics

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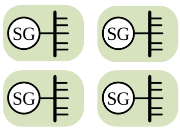
Early grids

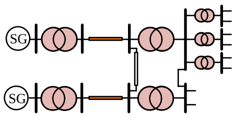
Battle AC vs DC → AC won



- Small electric islands
  - Different f, U
- Short distance
- Radial

Bigger is better

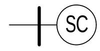
Power system



- Large grid
- Large power stations
- HV transmission lines
- Meshed grids
- Passive loads

Stable

- First swing stability issues
- Avoid voltage collapses
- Avoid inter-area oscillations



Synchronous Condensers

- Increase short-circuit power
- Control voltage level

- Power electronics
  - Static Var Compensators (thyristors) 1975 →

Sensitive loads in power system

- Automation (computers, …)
  - Cost of low power-quality increases
- Power electronic loads (thyristor and diode rectifiers)

- Mitigate and ride-through voltage dips
- Mitigate voltage and current harmonics

- Active power filters
- Reactive power compensation
  - SVC (thyristors) → STATCOM (transistors)

Today's power system

- Large amount of power electronic loads
- Introduction of distributed renewables using power electronics interface
  - Solar PV and wind turbines
- Increased use of HVDC transmission links

- Lower short-circuit power
- Risk of interaction between converters

- Need robust controllers for converters

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Mega-trends affecting power system

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Focus on grid-connected power electronics

Climate change

- Need to reduce CO2 emissions
  → Energy transition
- Political will to close down traditional power plants
- Increase of renewables in both distribution and transmission grids

Urbanization

- More than half of the world's population lives in cities today (2030: 60%; 2050: 70%)
- Number of mega cities (>5 million) increases
- How will the future power system for mega cities develop?
- Compact and invisible power distribution

Electrification

- Electricity consumption growing at twice the rate of overall energy (mainly in emerging countries)

Automatization and digitalization

- As economies digitize, the cost of non-performance of electrical system is increasing (>70% of problems occur in distribution part)
- Number of data centers will continue to increase

Fossil-free transportation

- Biofuels will preserve today's infrastructure
- A complete shift to electric vehicles will set tough demands on infrastructure
  - Batteries (slow and fast chargers affect distribution system)
  - Electrified highways (catenaries, electric tracks on road, inductive charging)

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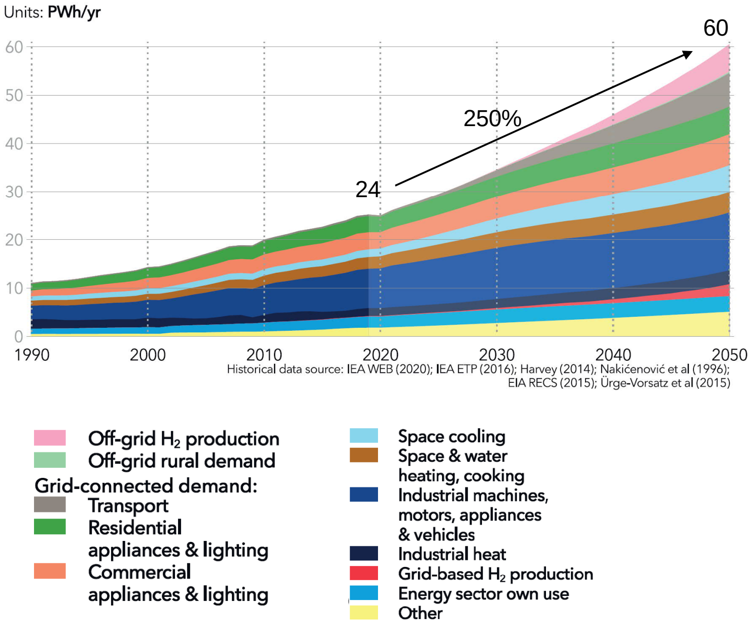
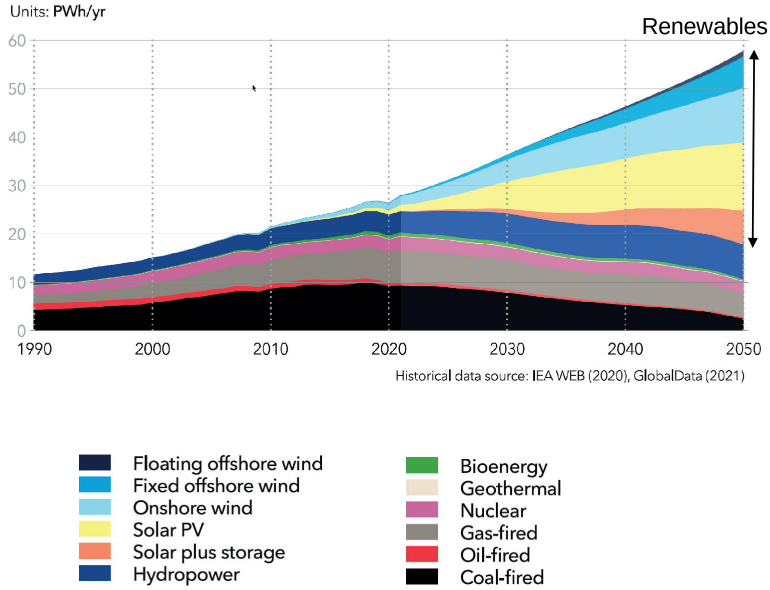
Scenario on energy transition up to 2050

Electricity demand by sector



Electricity generation by power type



from DNV "Energy transition outlook 2021"

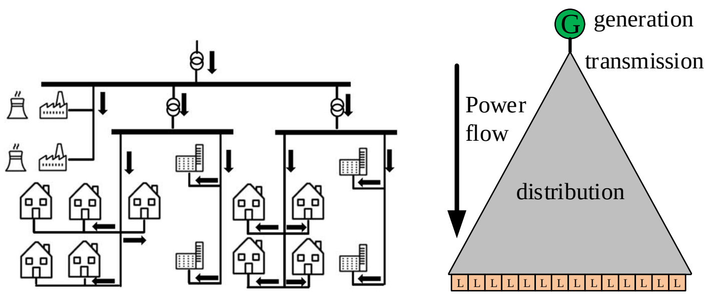
Change in grid structure

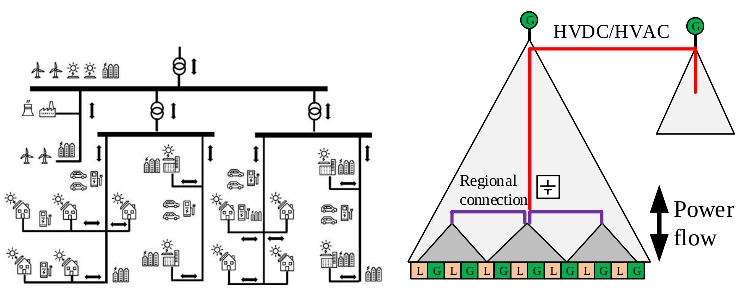
Old grid structure

- Uni-directional power flow
- Passive loads
- Loads consuming energy

Future grid structure

- Bi-directional power flow
- Passive and active loads that consume/generate/store energy
- Renewables (distribution and in utility scale)
- More distribution and regional grids w/ regional interconnections
- Energy/power balancing: ESS together with long transmissions, demand response, renewable curtailment and flexible power stations
- Moving loads
- Add intelligence





Example 1: Mitigate low inertia (SVC Light Enhanced)

Future power grid challenge

Power system inertia

European inertia 2030 scenario

Traditional value: 5 to 6 s

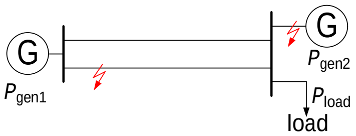
- Green H ≥ 4 s Very good contribution
- Yellow 3 s ≤ H < 4 s Good contribution
- Orange 2 s ≤ H < 3 s Marginal contribution
- Red H < 2 s Limited contribution

Source: ENTSOe “Ten year network development plan TYNDP2016”

Issues with low power system inertia and solution

Problem?

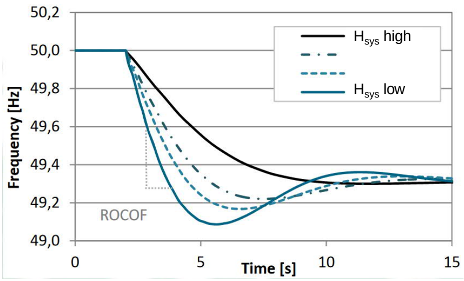
- When closing down traditional power plants using large synchronous generators grid stability issues can occur
  - Lower inertia
  - Lower short-circuit power
- Power system fault resulting in reduced generated power (power plant or line)



- Power imbalance results in reduced frequency
- At too low frequency, loads and generations are disconnected from power system

Frequency variations

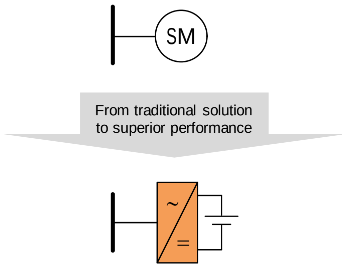
- Low inertia results in quicker frequency variations



- By adding inertia, stability can be increased
  - Synchronous Condenser with rotating mass is a traditional solution

Grid forming

- Enhanced STATCOM with small energy storage and with overload capability utilizing an advanced controller can increase performance



- A proposal from ENTSOe is that almost all grid connected generators must behave like a synchronous generator (inertia and overload capability)

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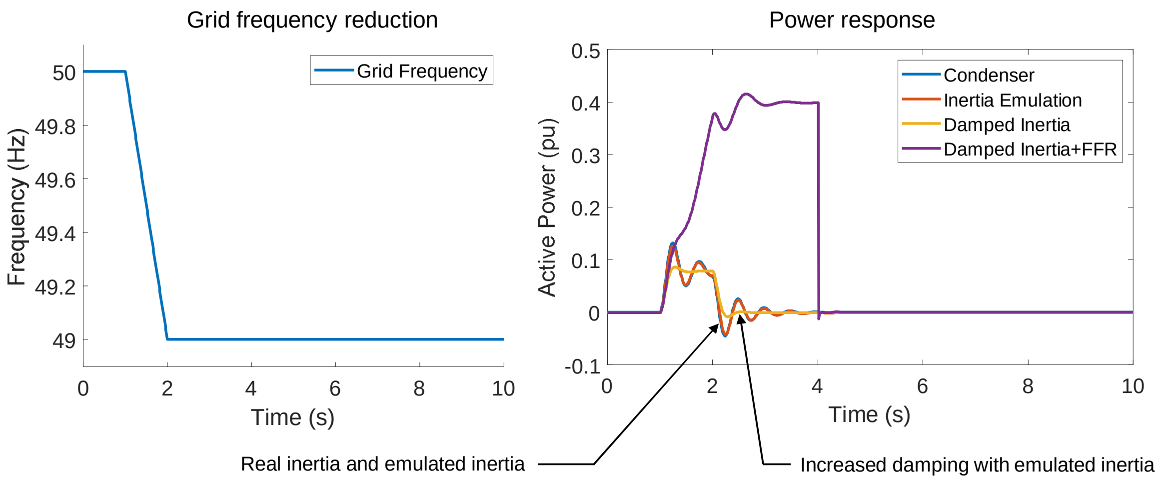
Frequency support performance

- Converter with storage can provide similar inertia and damping as synchronous machines
- Converter with storage can provide better performance than synchronous machines:
  - Adjust damping factor based on grid strength and operation point
  - Very high inertia constant
  - Combination of fast frequency response and inertia response



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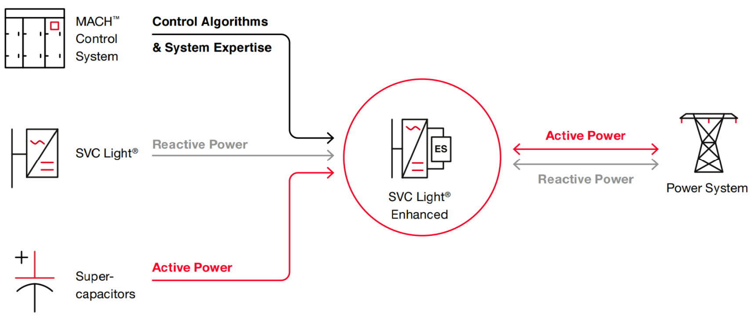
SVC Light® Enhanced

Concept of an Enhanced STATCOM



Multiple services for future grid stability

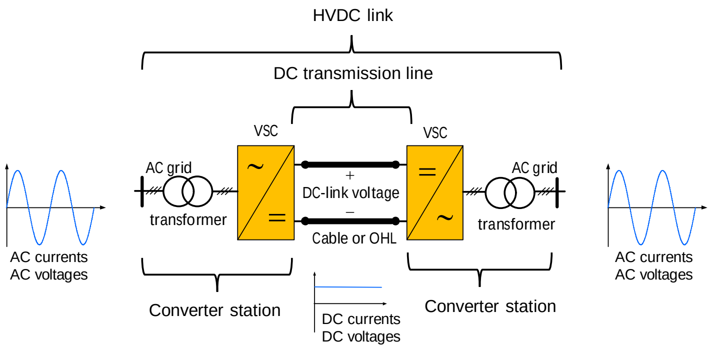
Grid-stabilizing services	Traditional STATCOM	Synchronous condenser	SVC Light® Enhanced
Voltage regulation	●●●	●●	●●●
Inertia		●●	●●●
Short-circuit contribution	●	●●●	●●
Flexibility/modularity	●●●		●●●
Controllability	●●	●	●●●

Example 2: DC transmission (HVDC Light)

HVDC History

- The commercial breakthrough came 1954 in Sweden: 20MW, 100kV cable link from mainland to island of Gotland using mercury-arc valves
- In 1970s thyristors were introduced for HVDC
- In 1997 self-commutated converters using IGBTs were launched for HVDC

Laying the Gotland cable in 1954



Why so high voltage?

- Need high DC voltage to reduce current → reduce DC-line losses

Why DC?

- No AC → Transmit power for a long distance with OHL & cables
- Decoupling of AC systems

HVDC Light

VSC HVDC

- Research project 1994
- Hällsjön 3 MW R&D demo 1997
- Gotland 50 MW Pilot 1999
- …

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HVDC Light® Up to ±640 kV & 3500 MW*

Valve hall of HVDC Light

The North Sea Link (NSL) interconnector between Norway and UK: 1,400 MW, ±525 kV, 730 km

* Technology adapted to ±640 kV and 3.5 GW. Highest DC voltage in operation is ±525 kV with power level 1.4GW

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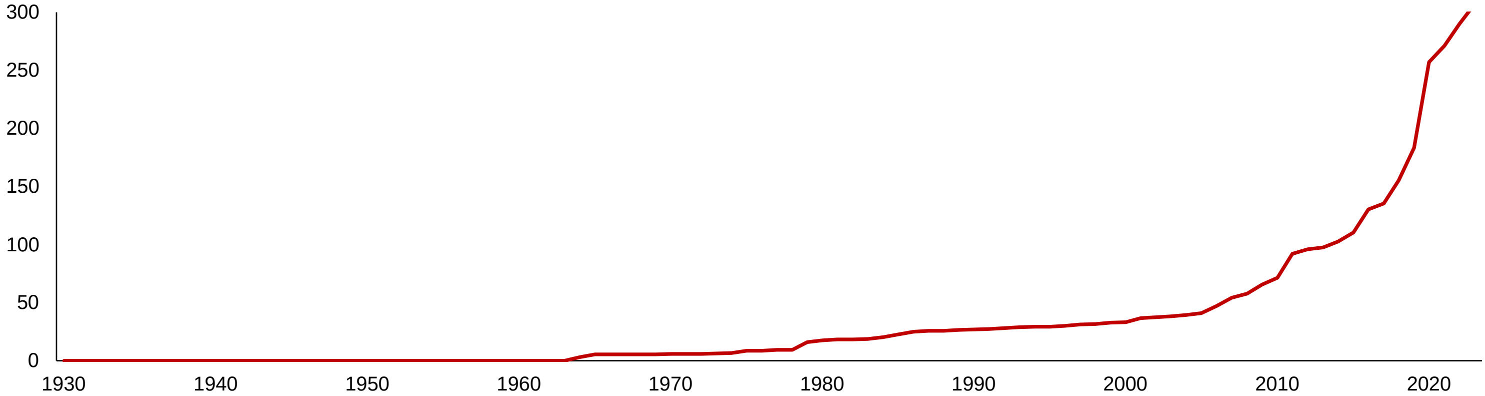
Cumulated GW installed



1928
Dr Uno Lamm began developing HVDC in Ludvika, Sweden

1954
The world's first commercial HVDC link at Gotland, Sweden

1970s
Mercury arc valves replaced with thyristor semiconductor valves

1997
The world's first VSC HVDC installation

2017
VSC HVDC highest performance ever – 3,000 MW, 640 kV, 2,000 km

Exponential growth has been driven by Technical developments and Grid transformation needs

Interconnecting Grids

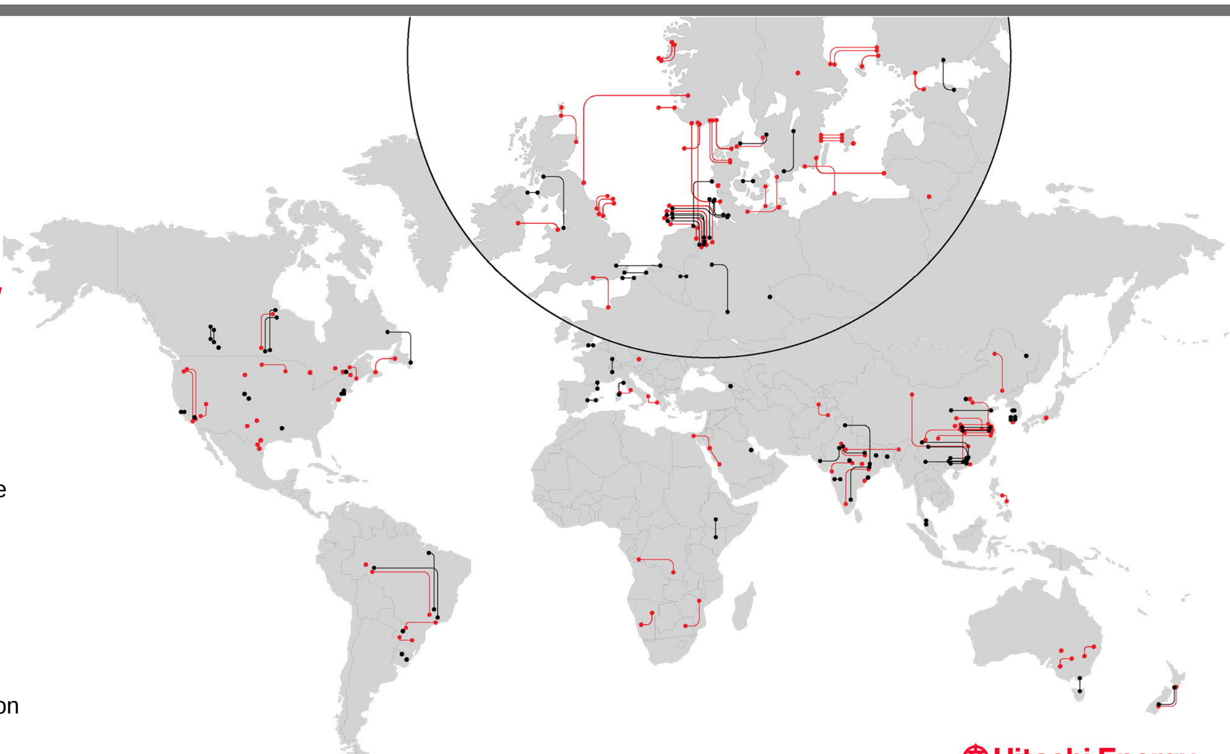
Heavyweight market

~3x
Growth rate vs. world GDP

~200 GW
Operating world Installed base

70%
World installed base equipped with ABB

Up to 12GW
Capacity range of one HVDC installation



HVDC applications

Shaping the grids of the future

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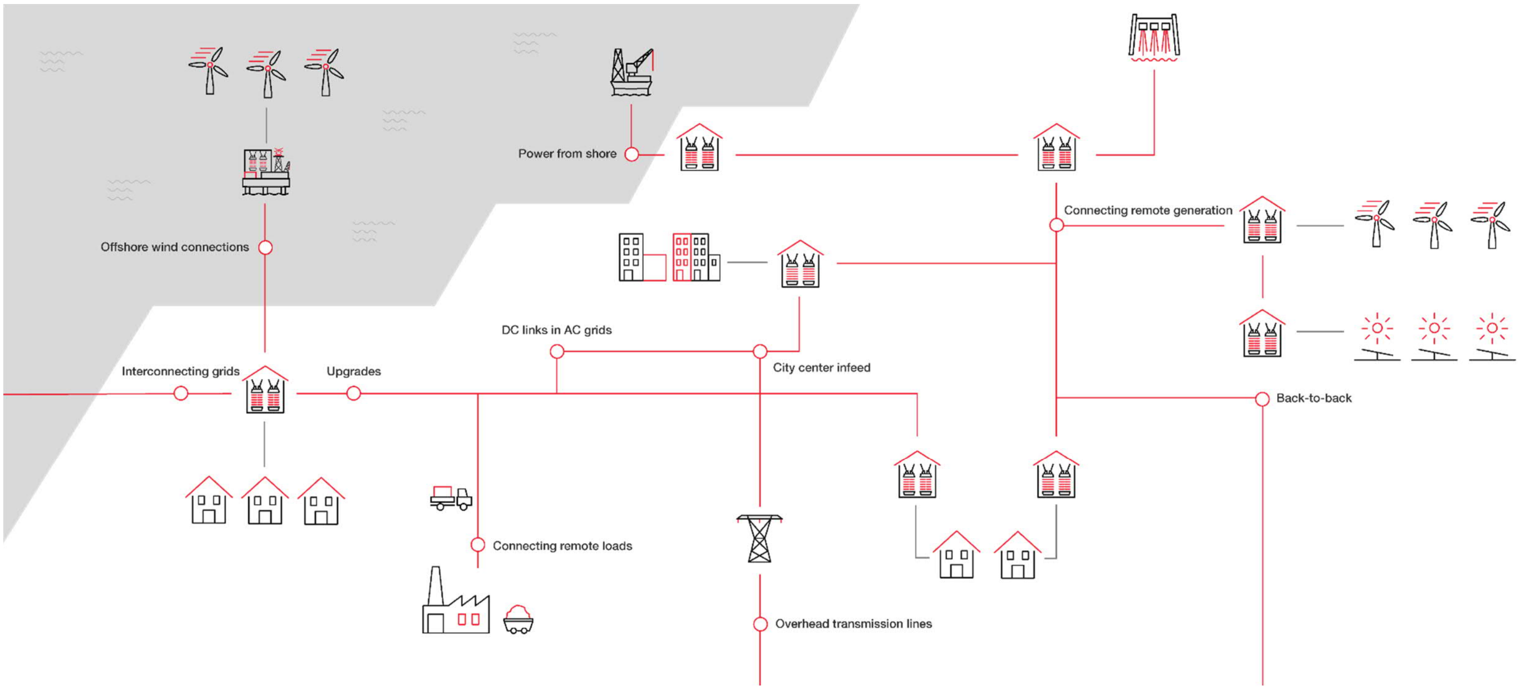

Public

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The first regional DC Grid in Europe

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Customer
Scottish Hydro Electric Transmission Ltd (SHETL)

Customer needs
- Strengthening power network

Our response
- Two HVDC Light® converter stations, 1,200 MW and 800 MW
- Submarine and underground cable transmission of nearly 160 kilometers

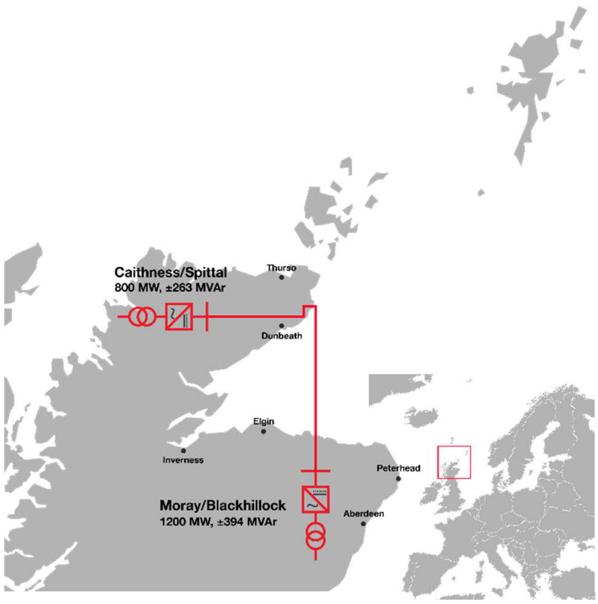
Customer benefits
- Enable integration of renewable energy
- Increased network stability

Year
2018

HVDC Light® converter stations

- Symmetric monopole ±320 kVdc
- Blackhillock: 1,200 MW
- Spittal: 800 MW

Land and sea DC cable system



Caithness-Moray-Shetland HVDC Link - Phase 1 - In operation

Public

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The first regional DC Grid in Europe

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Customer
Scottish and Southern Electricity Networks (SSEN) Transmission

Customer needs
To link Shetland to the UK transmission system

Our response
- First multi-terminal HVDC interconnection in Europe, with option of two more terminals
- 600 MW ±320 kV

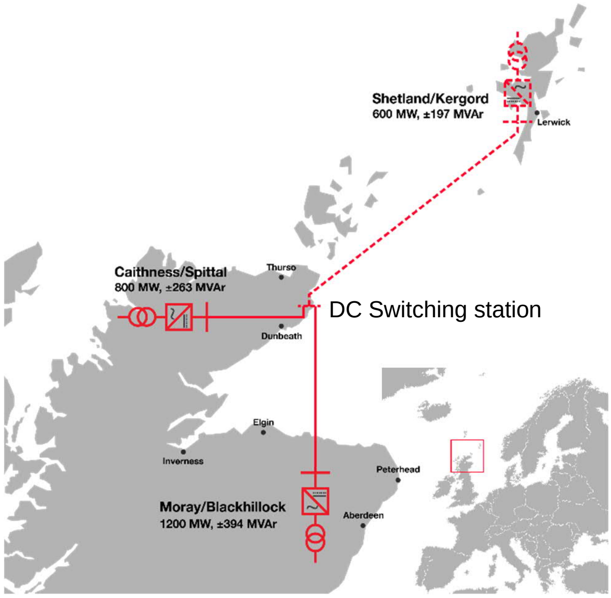
Customer benefits
- Multi-terminal HVDC interconnection provides flexibility to transfer power in multiple directions, based on supply and demand, with minimal power losses
- Boost renewable energy and enhance security of power supply
- Help to connect and transmit wind power generated on the islands to the UK
- Contribute to bringing all greenhouse gas emissions to net zero by 2050

Year
2024

HVDC Light® converter stations

- Symmetric monopole ±320 kVdc
- Blackhillock: 1,200 MW
- Spittal: 800 MW
- Kergord: 600 MW

DC Switching station at multi-terminal connection point



Caithness-Moray-Shetland HVDC Link - Phase 2 – Under construction

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Future scenarios - Offshore wind expansion

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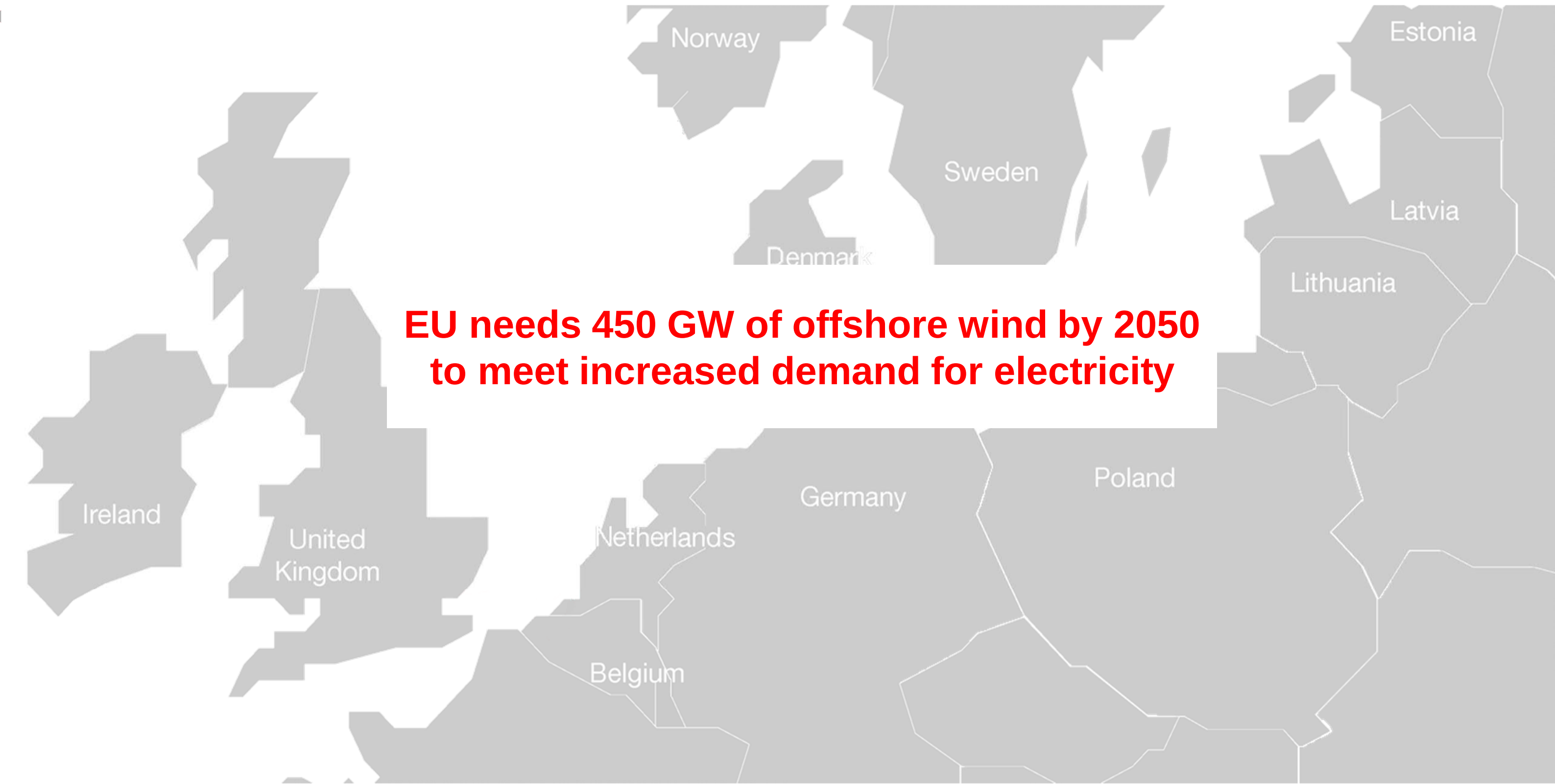
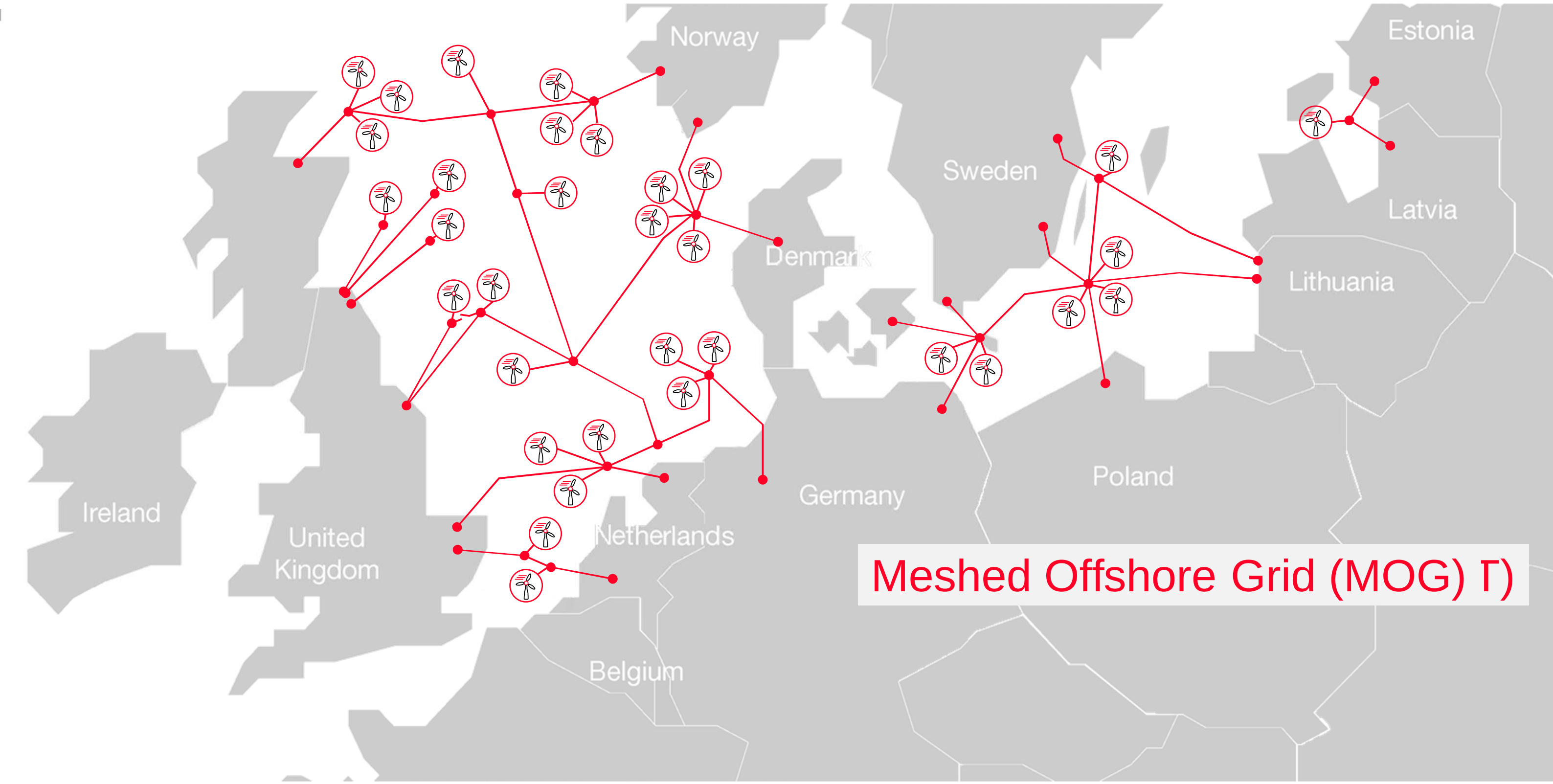


EU needs 450 GW of offshore wind by 2050 to meet increased demand for electricity

Future scenarios - Offshore wind expansion



Future view of power electronics across the total power system

Future view of power electronics across total power system

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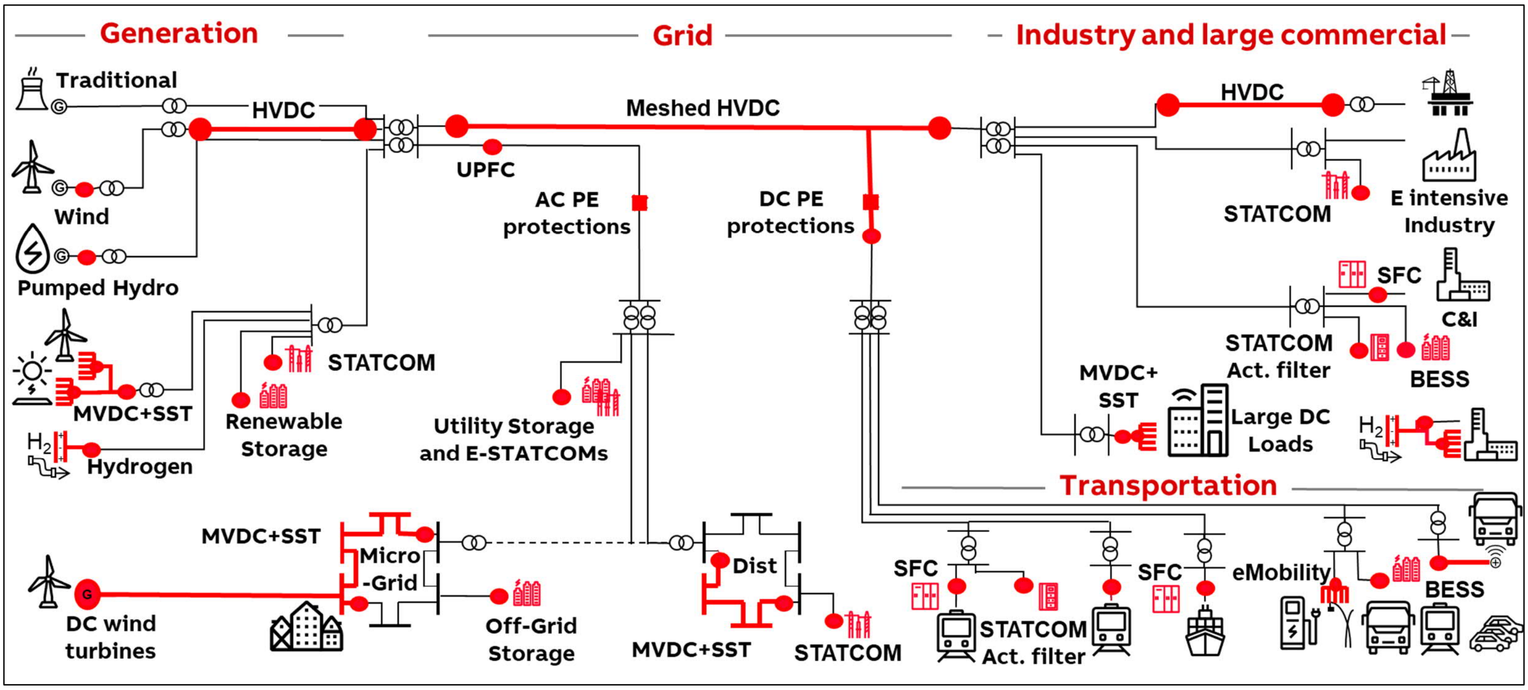

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Summary

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Energy transition is ongoing

- Increased electricity consumption → Increased electricity production

Grid structure changes

- From top-down towards an advanced inter-connected grid with active loads/generations

Power electronic examples in power system that supports energy transition:

  - SVC Light Enhanced: STATCOM with energy storage that also provides inertia
  - HVDC Light: Interconnect power systems, generations and loads

- Hitachi Energy is advancing the world's energy system to be more sustainable, flexible and secure

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