Sailing into a Greener Future: Power Electronics at the Shore and in the Ship

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POWER ELECTRONICS
Power Electronics & Energy Storage event
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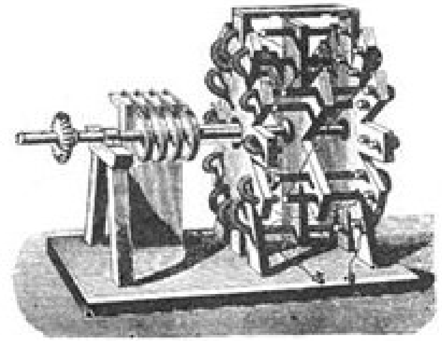
ENERGY STORAGE

Contents

Source: Ørsted

Battery-Powered Ships: not as new as you would think!

- 1832: William Sturgeon invents the DC motor
- 1839: M.H. von Jacobi designs first E-Boat (4 kmph, 1 kW)
- 1867: Nikolaus Otto invents the IC engine
- 1889: Siemens & Halske design Elektra (15 kmph)
- 1920: US Navy goes diesel-electric for ships
- 1947: The BJT is invented at Bell Labs
- 1973: The MARPOL convention is adopted
- 1991: SONY introduces commercial Li-ion battery
- 2000: Gothenburg has the first 50/60 Hz HVSC
- 2015: MF Ampere sets sail with 1 MWh capacity
- 2022: Container ship Yara Birkeland is launched (7MWh battery)


Jacobi's DC motor

Siemens Elektra, 1886


Schottel azimuth thrusters

Replica of 1st BJT


ABB shore connection, Rotterdam, 2012


MF Ampere, 2015


Yara Birkeland, 2022

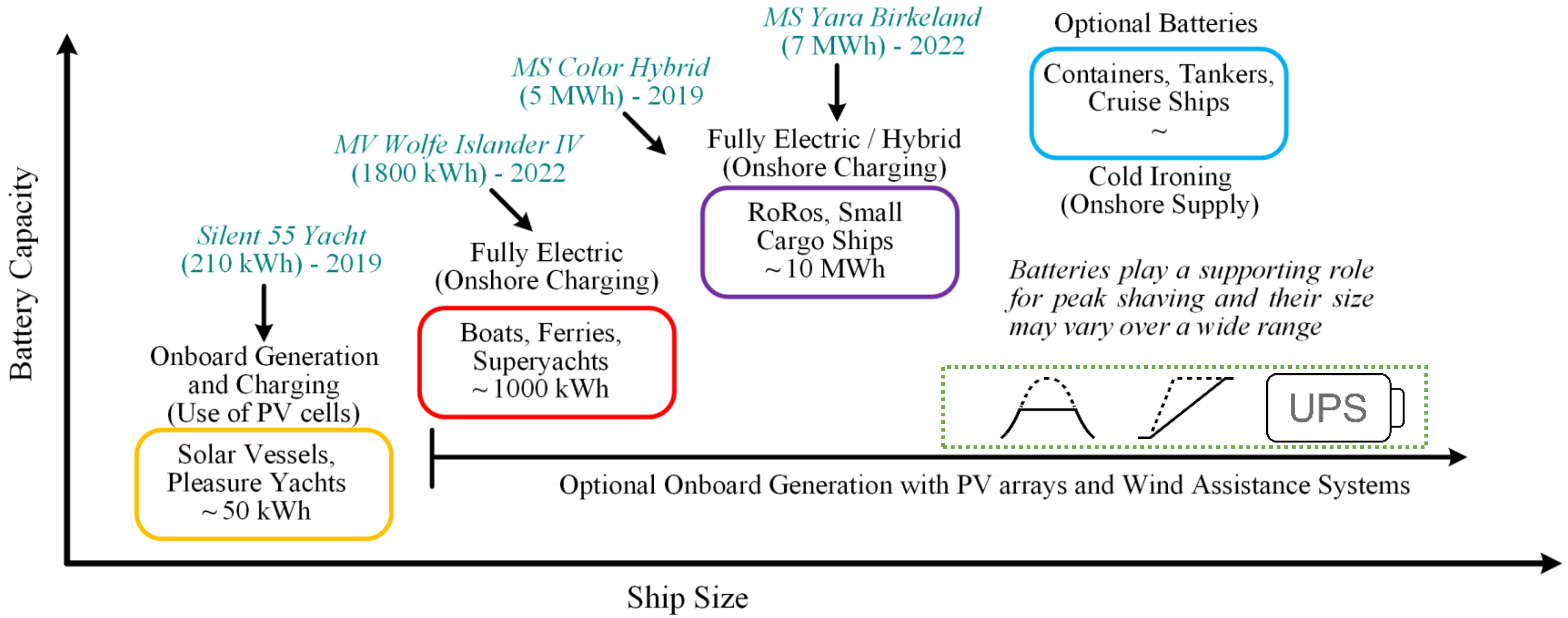
The Spectrum of Electrification Today


Solar Boat Twente

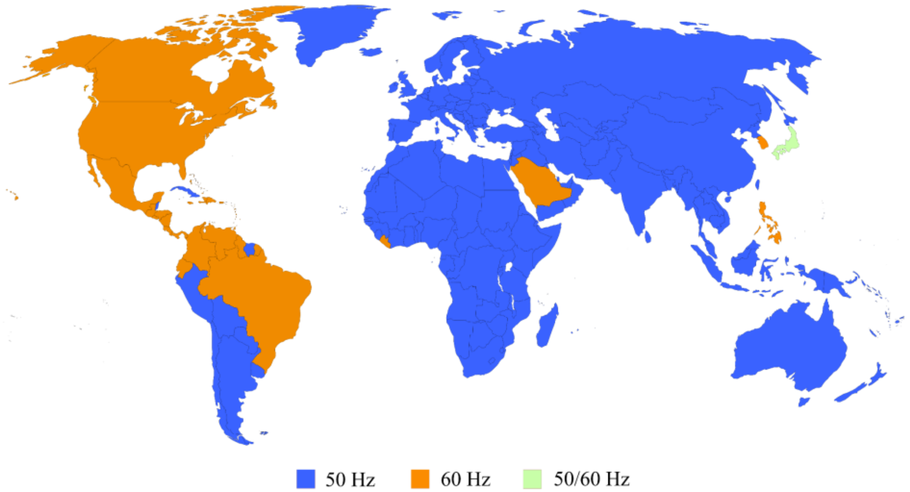

Wolfe Islander IV


Yara Birkeland

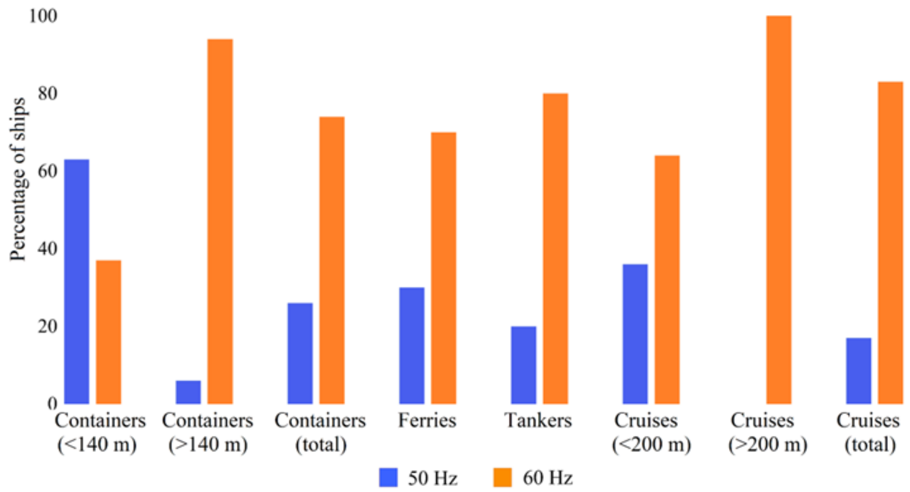

Wonder of the Seas



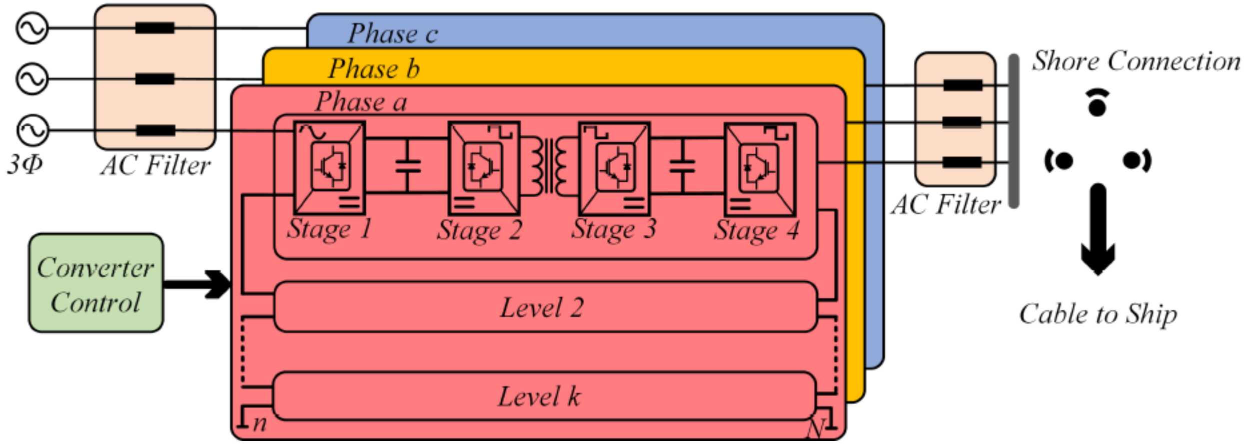
Why Cold Ironing needs PE?



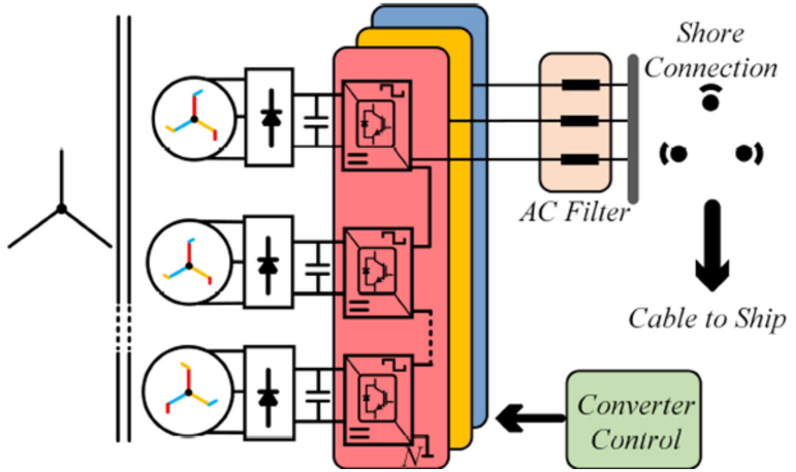
Frequency of mains electricity by countries across the world



Frequency of onboard power systems for various ships



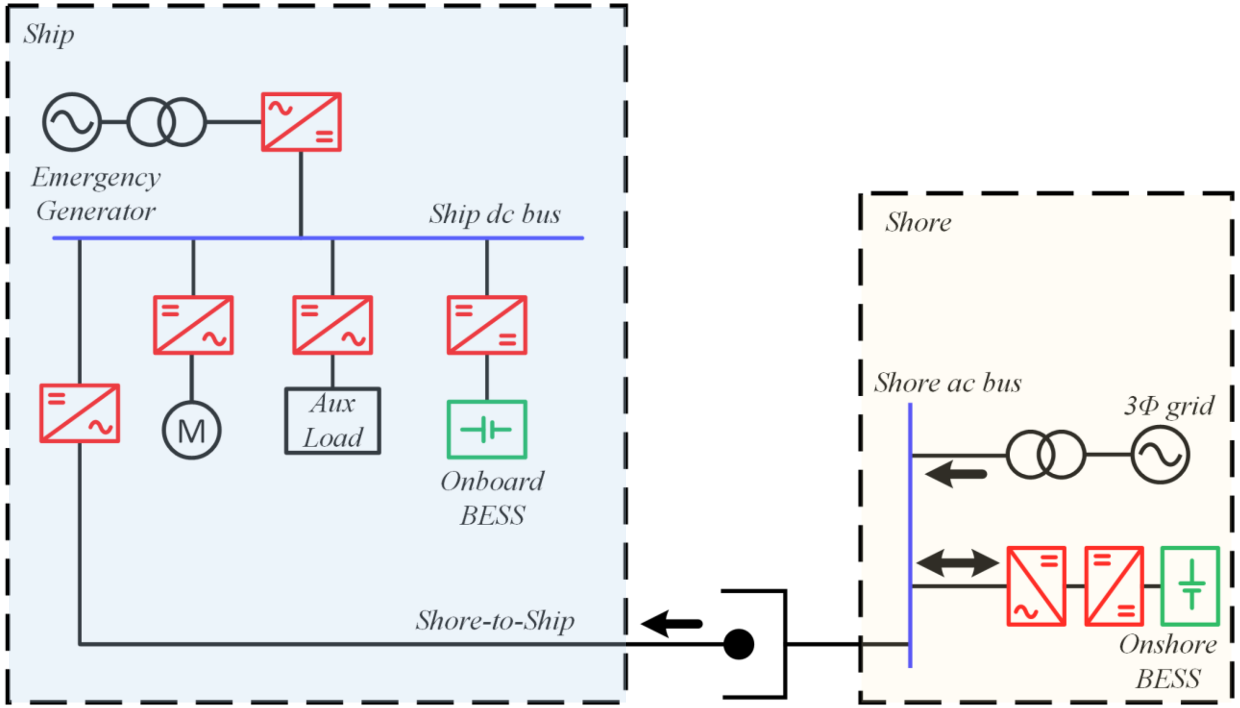
MF Isolation-based solution



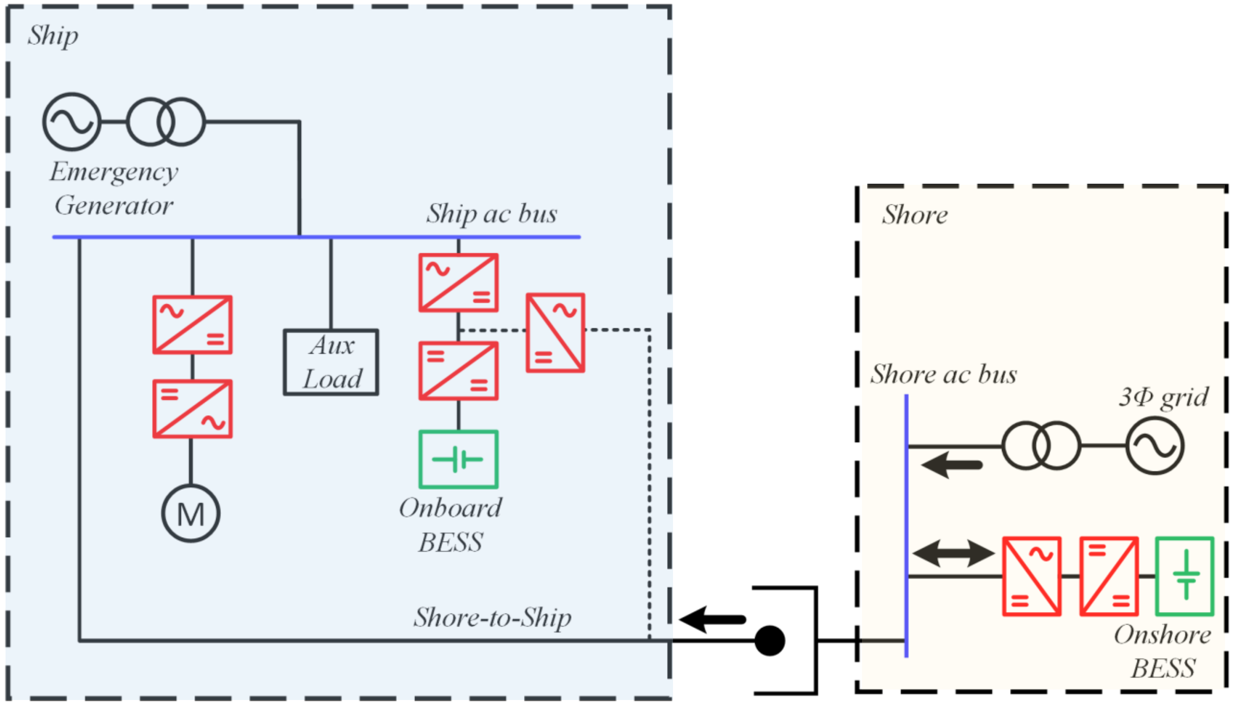
LF Isolation-based solution

Power Electronics in Shore-to-Ship Charging

- Charging from an AC Shore Bus



dc-based propulsion system

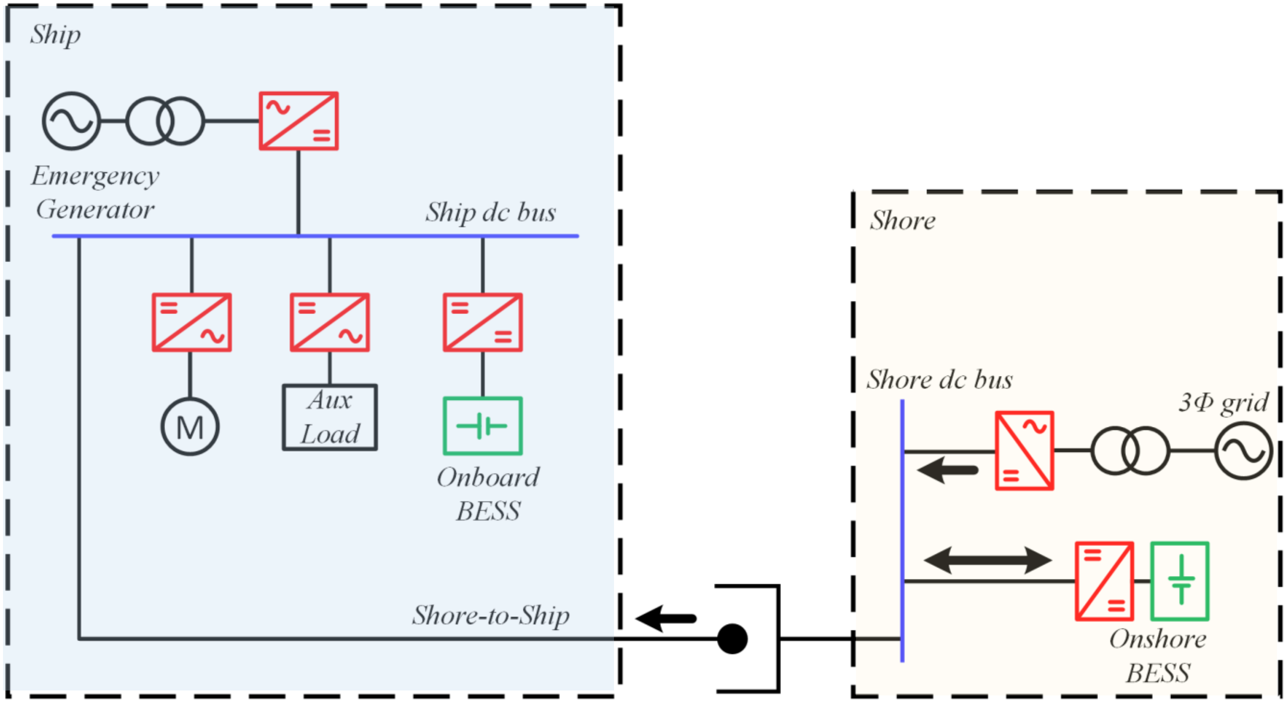


ac-based propulsion system

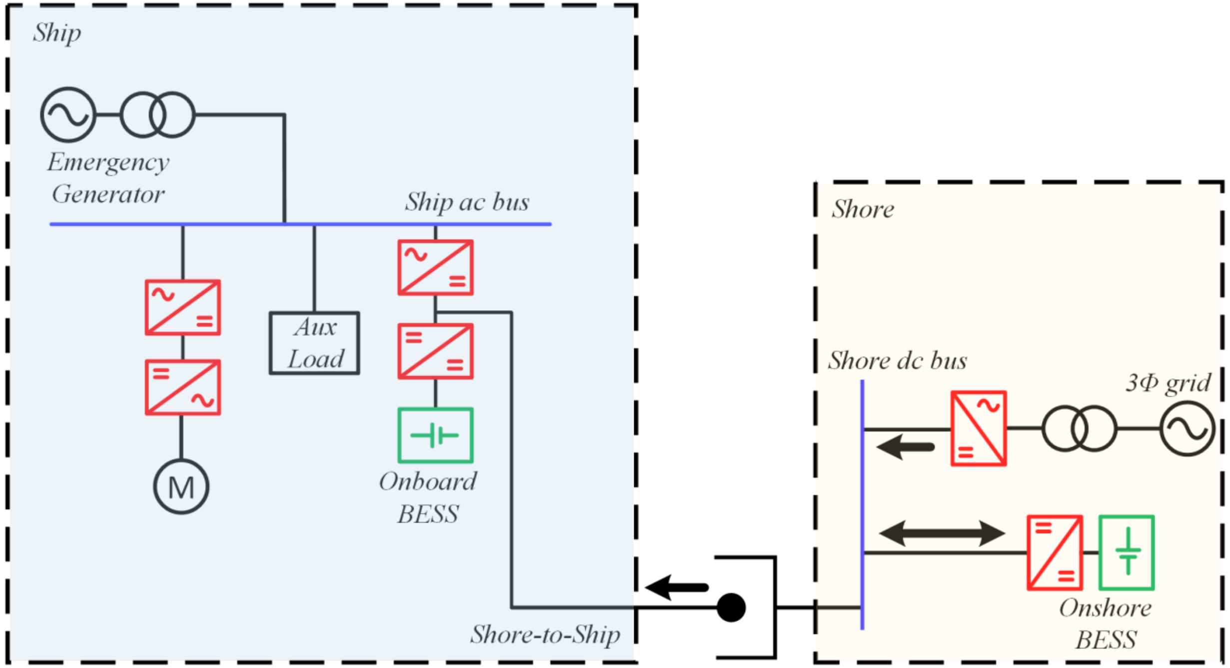
- For vessels where charging infrastructure is not available at the shore
- Similar to OBCs in electric cars
- Synchronization is needed for ac-ac connections

Power Electronics in Shore-to-Ship Charging

- Charging from a DC Shore Bus



dc-based propulsion system

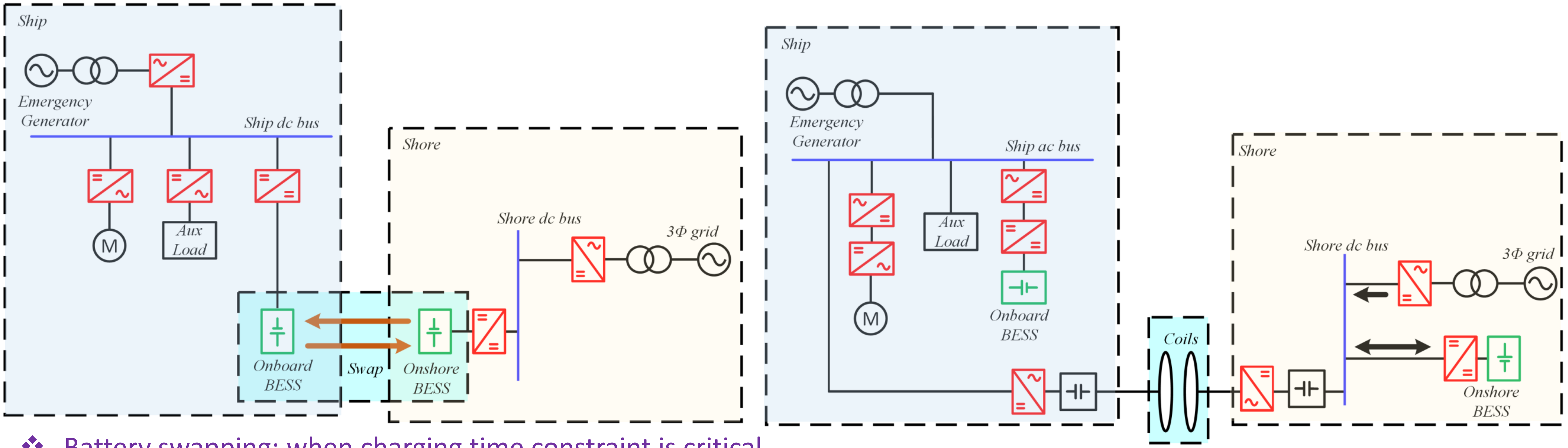


ac-based propulsion system

- Faster charging as compared to ac shore bus (high power charging station can be used)
- Power conversion stages are minimized onboard
- Most common scheme of charging boats and ferries

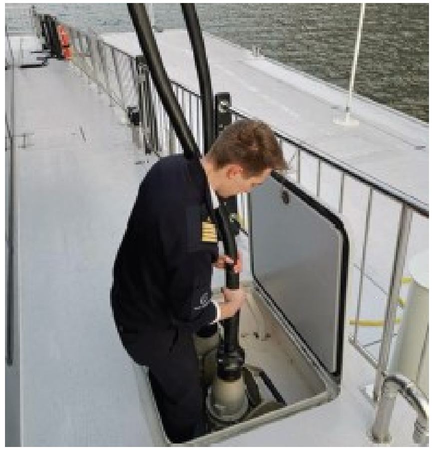
Power Electronics in Shore-to-Ship Charging

- Battery Swapping and Wireless Charging



- Battery swapping: when charging time constraint is critical
- Requires surplus batteries, moving equipment, etc.
- Inductive power transfer: suitable for vessels with short and frequent stops
- Challenges of misalignment, onboard weight, poor efficiency, etc.

Practical Implementations



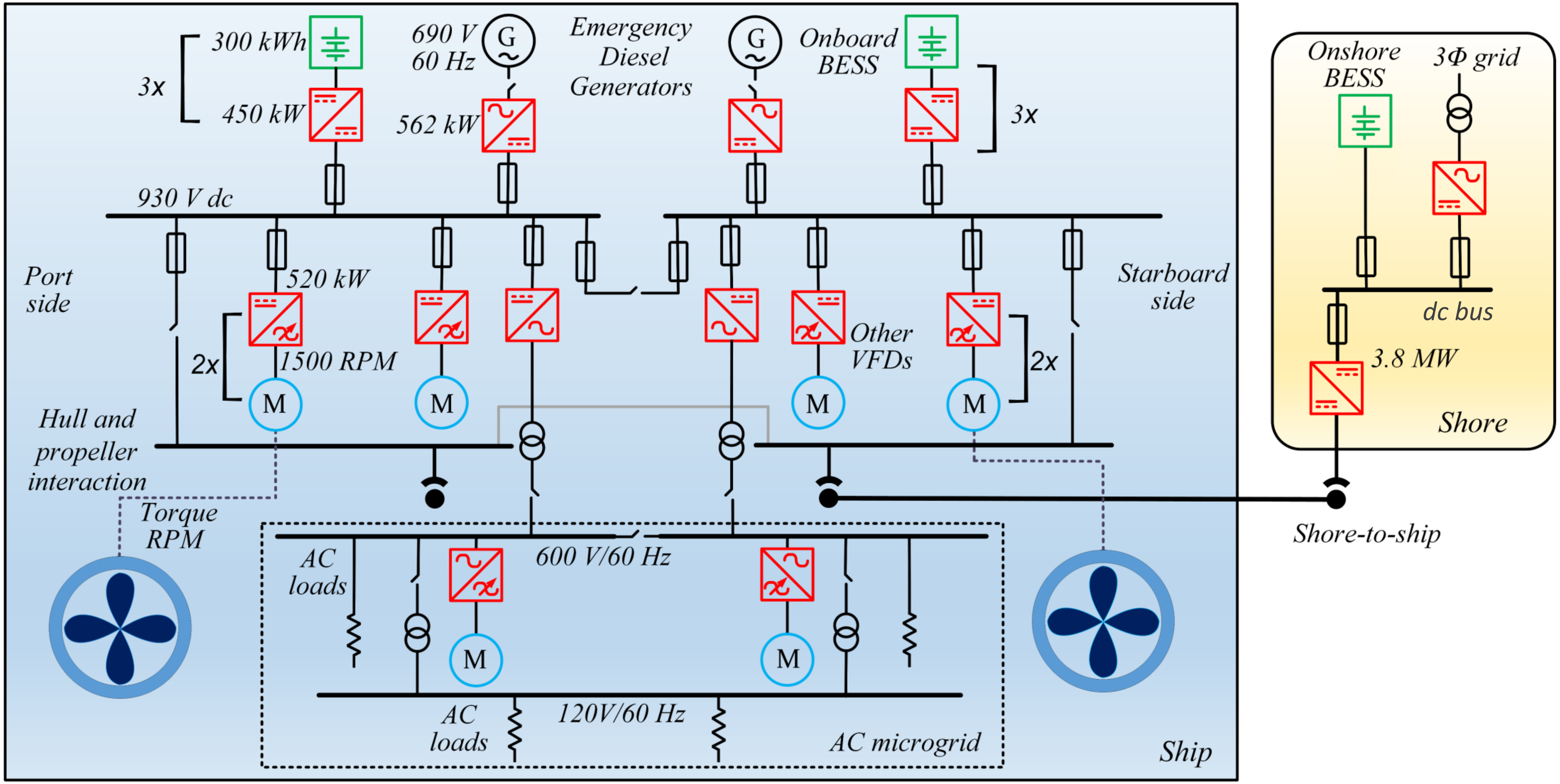
Manual connection of two cables for charging
(Source: Severin Synnevag)

An autonomous robotic arm used for charging
(Source: ABB)

Battery Container Swapping Solution
(Source: Bakker Sliedrecht)

The Wärtsilä inductive charging system for charging the MF Folgefonn
(Source: Wärtsilä)

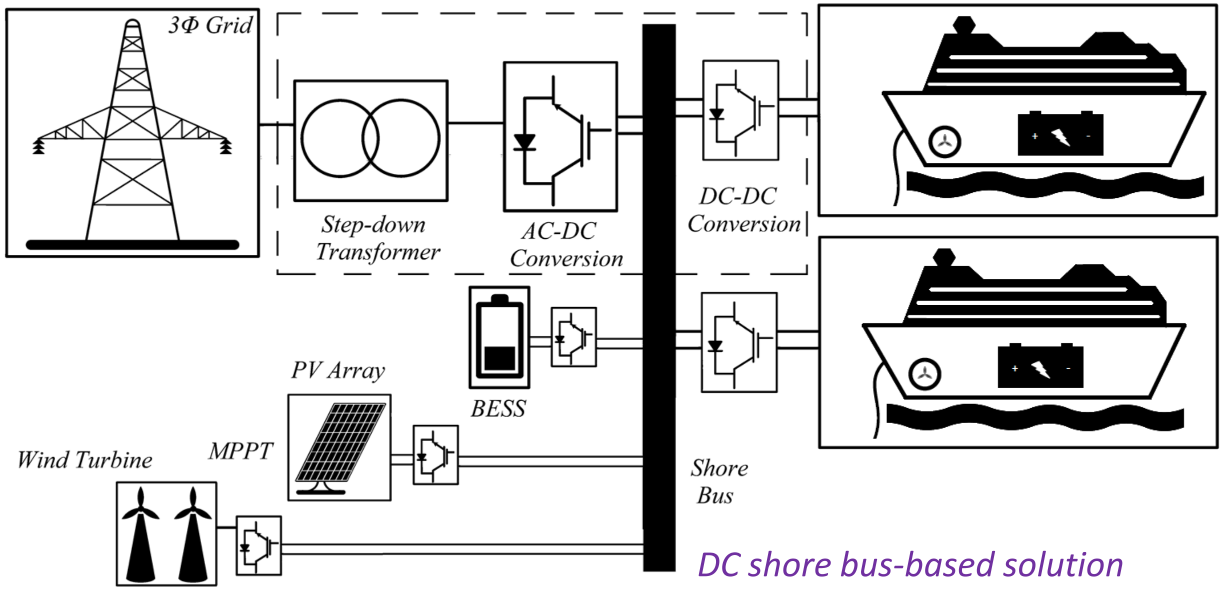
The Complete Shore-to-Ship PE Interface



Damen Wolfe Islander IV, Shore-to-Ship Power Electronics

Making the Onshore Station Multifunctional

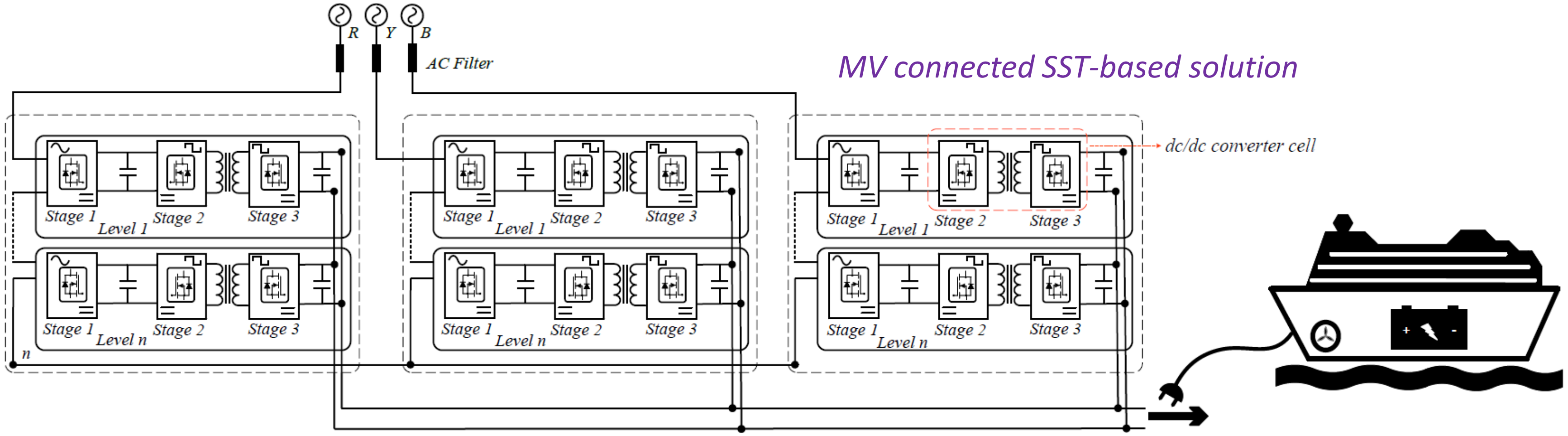
- DC shore bus makes it easier to integrate supplementary power and onshore batteries
- SST based-topology can offer a compact solution fed from a MV grid directly
- In both cases, the back-end DC-DC converter plays an important role in power delivery to the ship
- Goal: To make the back-end converter compatible with different DC ships, wide voltage compatibility is desired



DC shore bus-based solution

Car + Ferry Charger, Floro, Norway

Source: evobsession.com

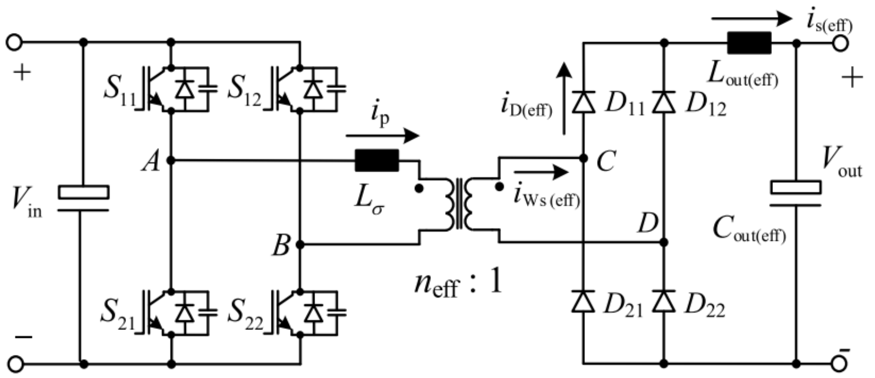


MV connected SST-based solution

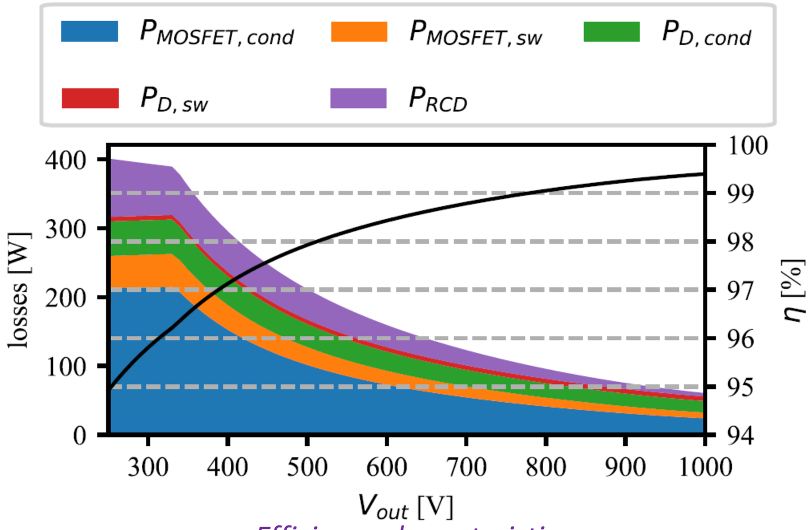
Back-End Converters

Phase-Shift Full-Bridge: Most Used Topology

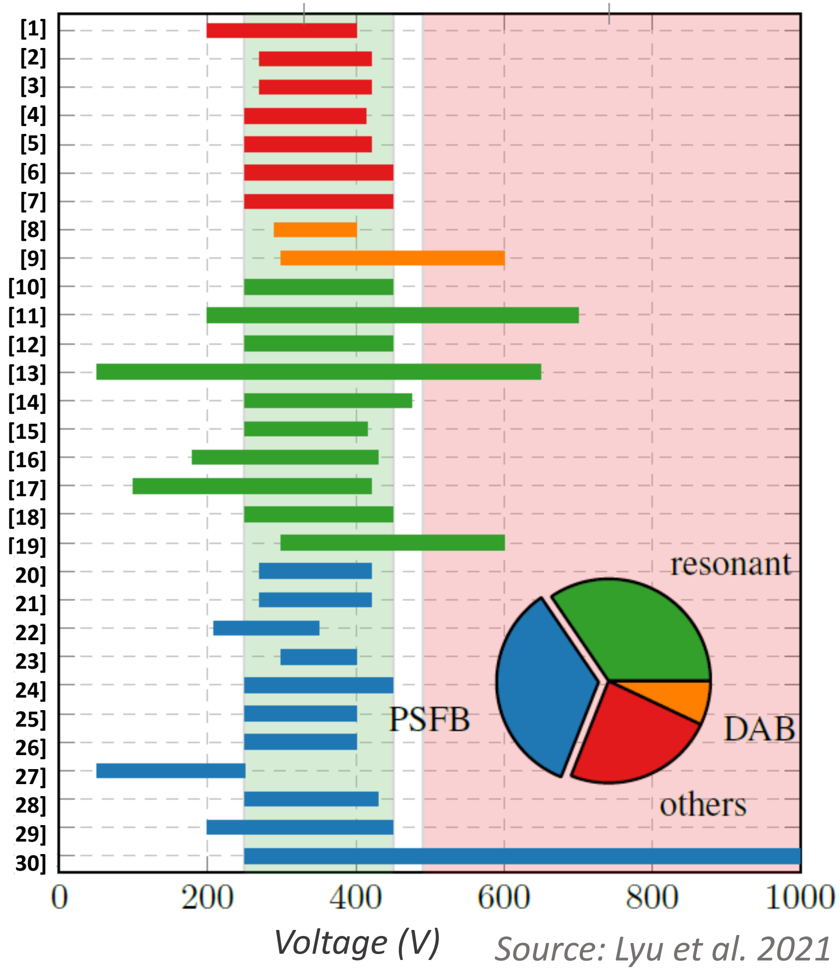
- Conventional phase-shift dc-dc converter: drooping efficiency characteristic
- Not possible to change the input voltage (shore-bus voltage is fixed)
- Onboard voltage variation can be extremely wide, LVDC: 400-1500V
- How to extend high-efficiency operation over such a wide output range?



Phase-Shift Full-Bridge



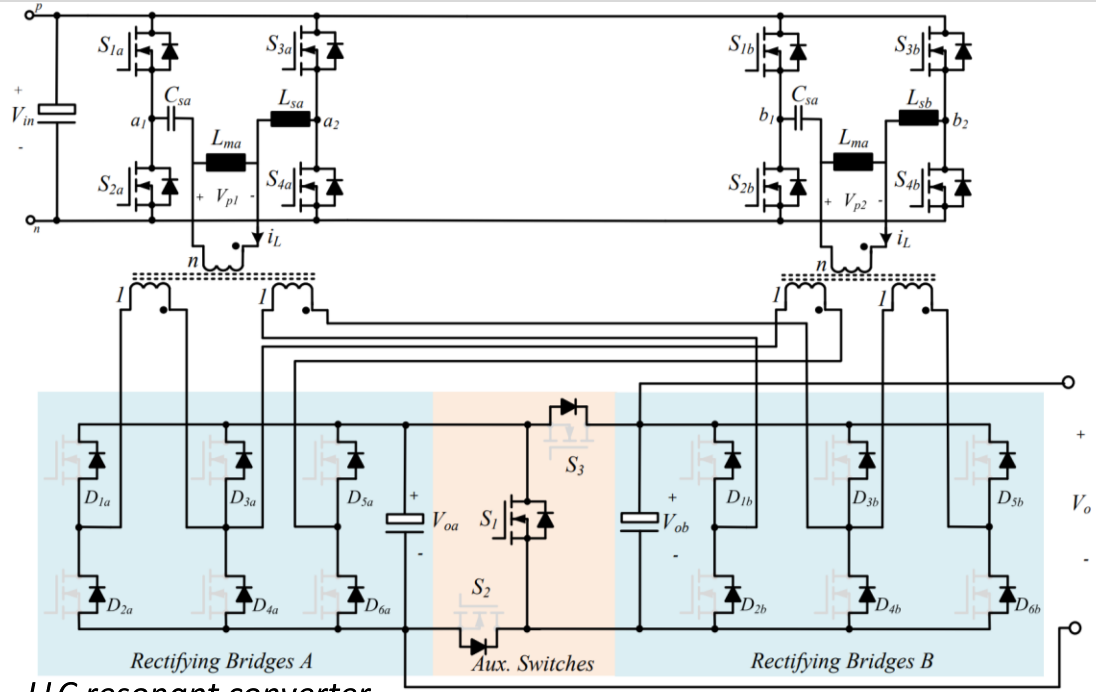
Efficiency characteristics



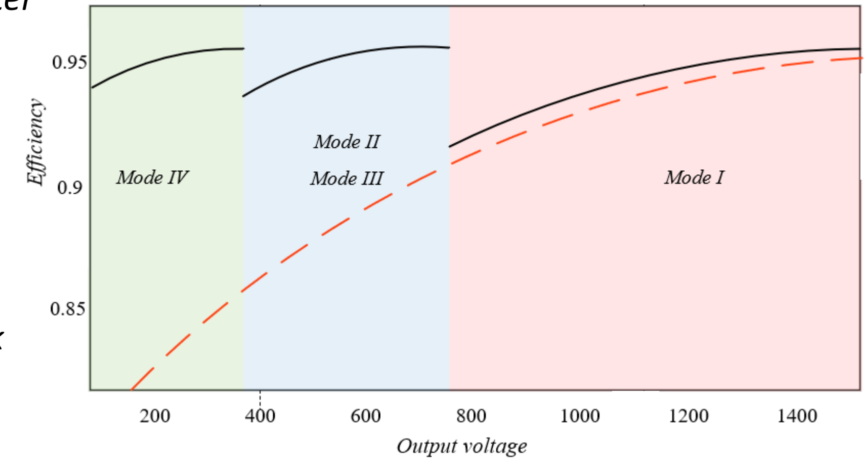
Source: Lyu et al. 2021

Output voltage ranges of the DC/DC converter prototypes reported in the literature from 2011 to 2022

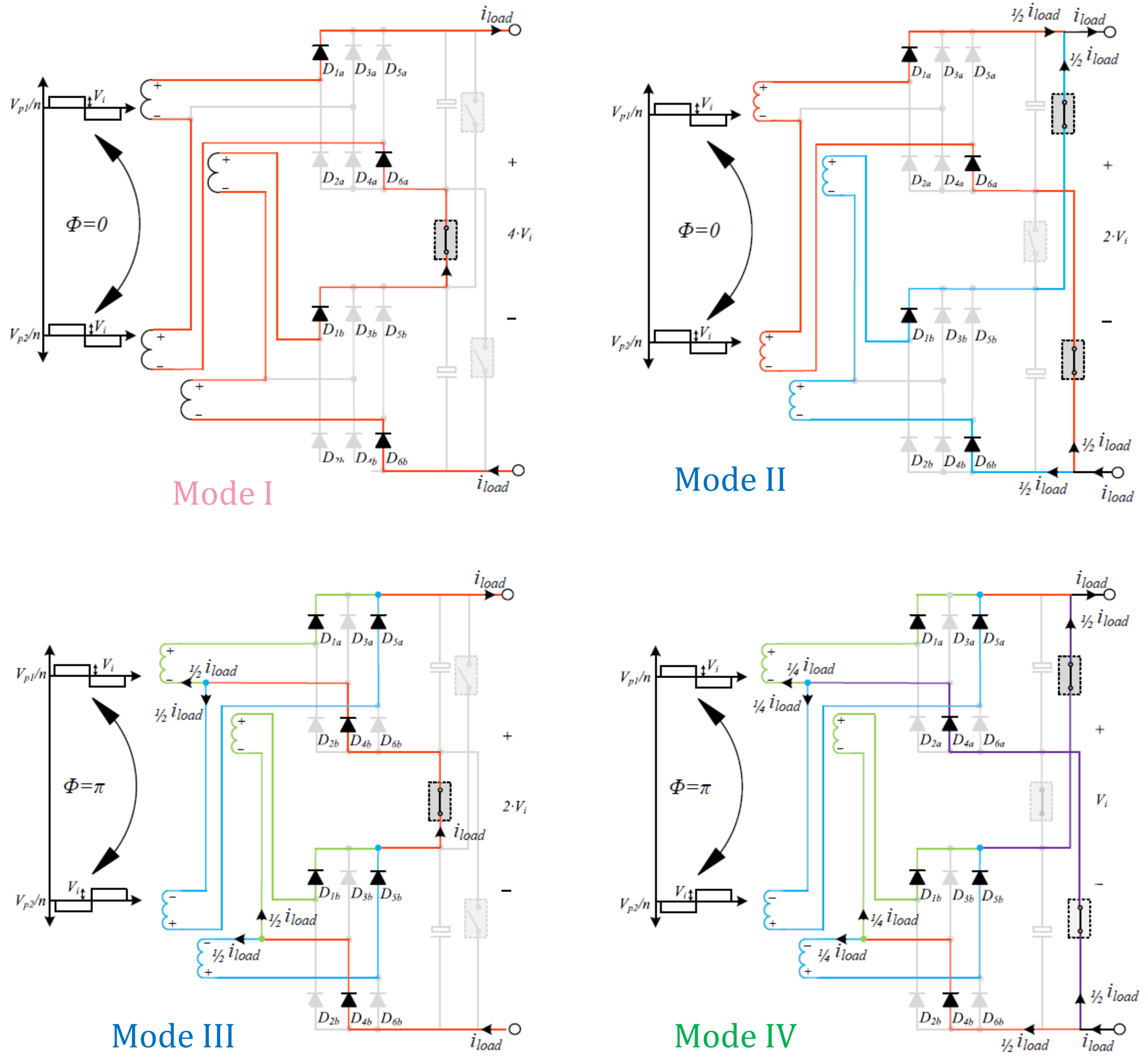
Developing a Wide Output Voltage Converter



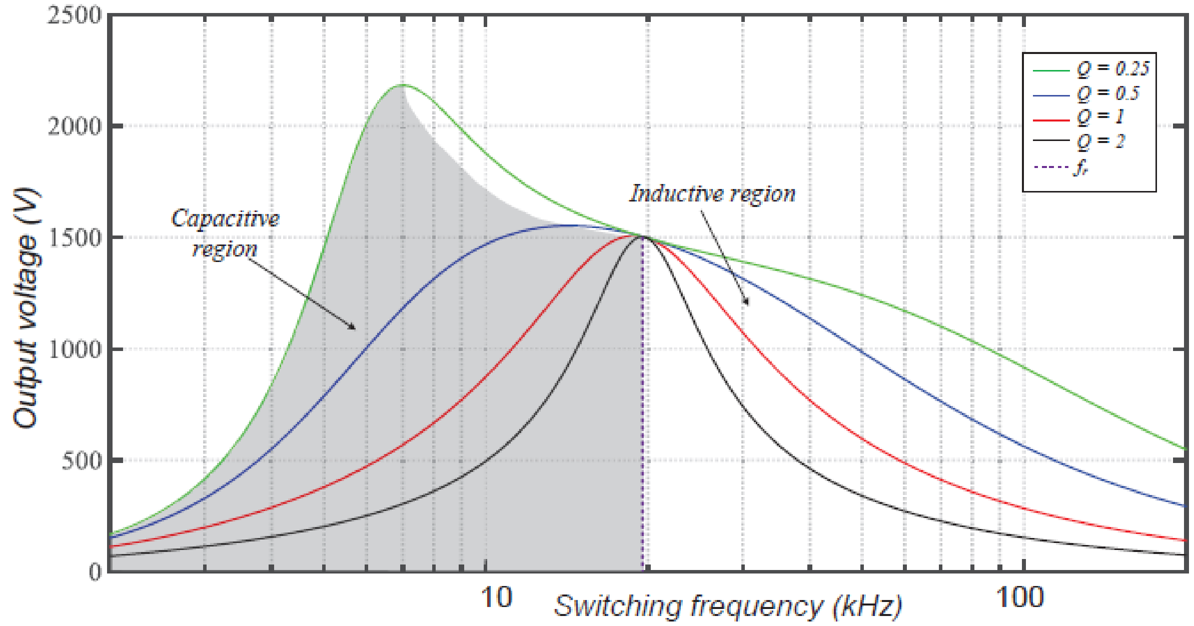
LLC resonant converter



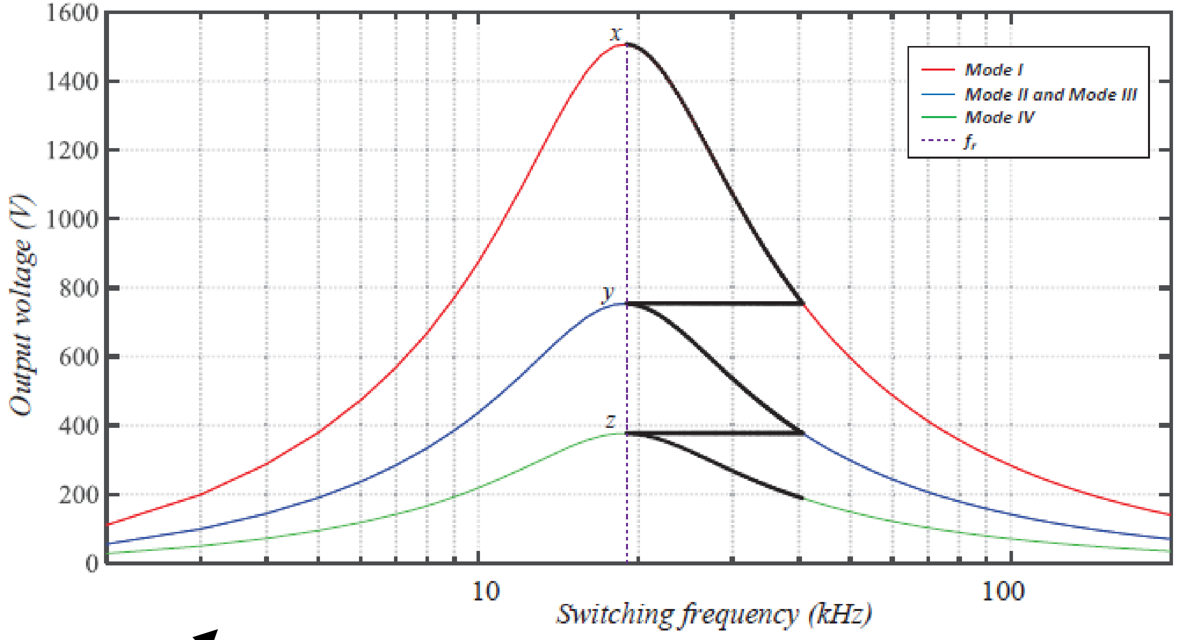
Idea: to have 3 peak efficiency points



Voltage Gain Characteristics



Variation of output voltage with switching frequency for different values of Q in a conventional LLC converter

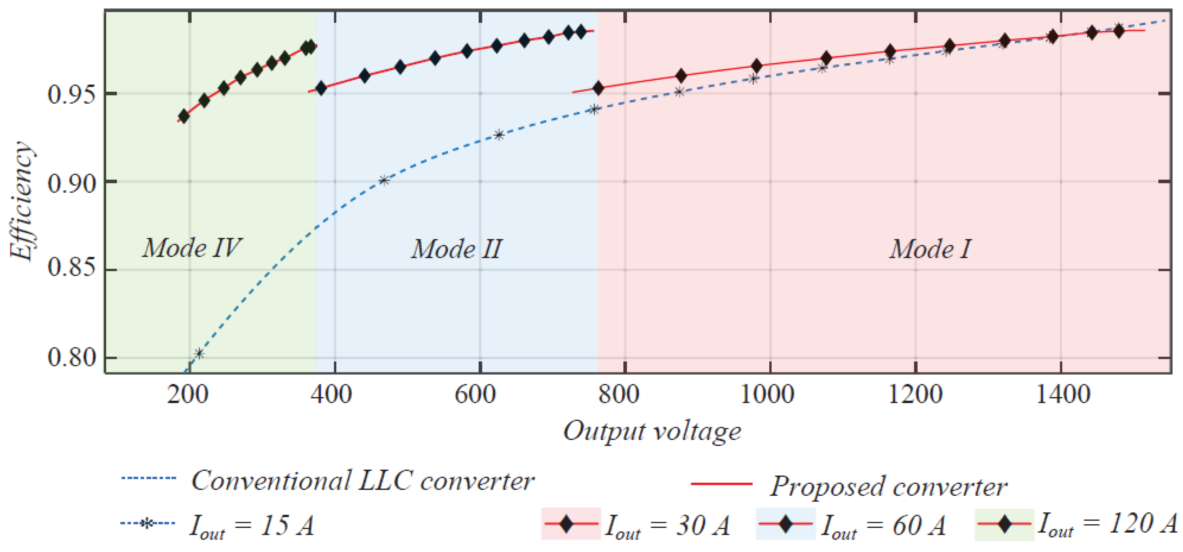


Variation of output voltage with switching frequency for different modes at Q =1

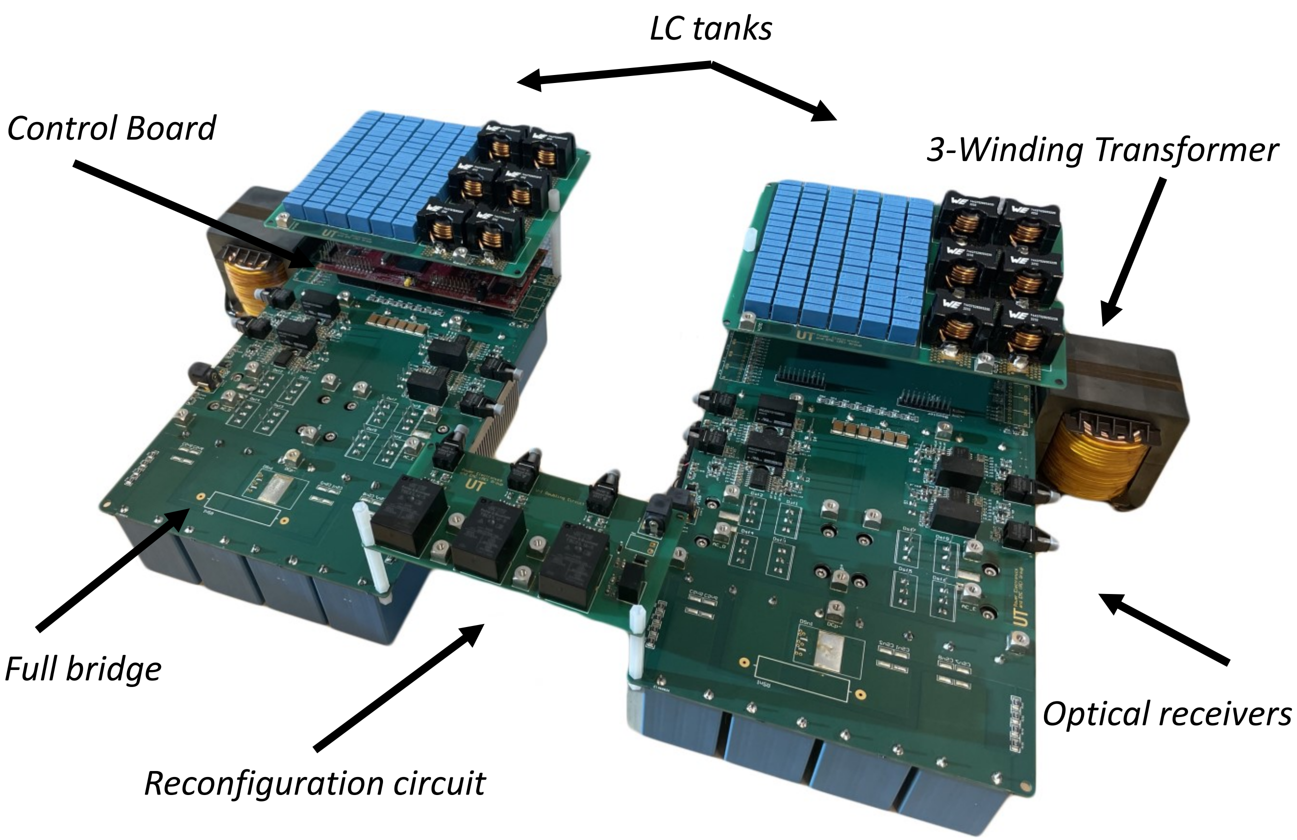
x, y, z represent points of same power output

Reconfiguration allows narrowing the switching frequency range

Some Initial Results



Efficiency Comparison (Simulated) of The Proposed Converter With a Conventional LLC Resonant Converter For Wide Output Voltage
PLECS thermal models are used



11 kW PCB-based prototype

Conclusion

- Battery-based transport is on the rise
- Onshore charging is a key element for transition towards efficient e-shipping
- Onshore battery charging can be done through wired, wireless or battery swapping methods
- DC-DC shore-to-ship connection offers the most flexibility, ease of implementation
- Back-end converters need to be adaptable for multifunctional operation
- Multifunctional onshore charging will accelerate the transition

Source: Ørsted

Questions?