IEEE PEAC 2022
The 3rd IEEE International Power Electronics and Application Conference

Electrification of Ship Based on Power Electronics

Nov. 6th, 2022
09:20 – 11:00

2022 Global Power Electronics Summit-2

Prof. Seung-Ki Sul
IEEE Fellow

SNU Power Electronics Center
Seoul National Univ.
Seoul Korea

Outline

Introduction :

Electric Propulsion Ship

Electric Propulsion Ship

❖ **History of worldwide marine electric propulsion**

USS New Mexico, 1917

https://en.wikipedia.org/wiki/Turbo-electric_transmission

Electric Propulsion Ship

❖History of worldwide marine electric propulsion

► Late 19th century

- ✓ Electric propulsion ship powered by battery in Russia, Germany, etc.

► 1910's

- ✓ Turbo-electric transmission used for transatlantic ocean linear.
- ✓ Diesel engine became prevalent by its technological advancement.

► 1970's

- ✓ Introduction of modern motor control
- ✓ SCR-based AC/DC rectifier for electric propulsion ship

Electric Propulsion Ship

❖History of worldwide marine electric propulsion

►1980's

- ✓ Advancement of power electronics and motor design
- ✓ AC/AC convertor for electric propulsion ship

►1990's

- ✓ Need of fuel economy, maneuverability, survivability, quietness
- ✓ Podded propulsion for icebreaker, cruise ship, etc.

►2000's

- ✓ 30~40% reduction of annual fuel consumption
  - Field support vessel, offshore construction vessel
- ✓ Royal Navy constructs every warship as electric propulsion.
  - Since early 2000's

Electric Propulsion Ship

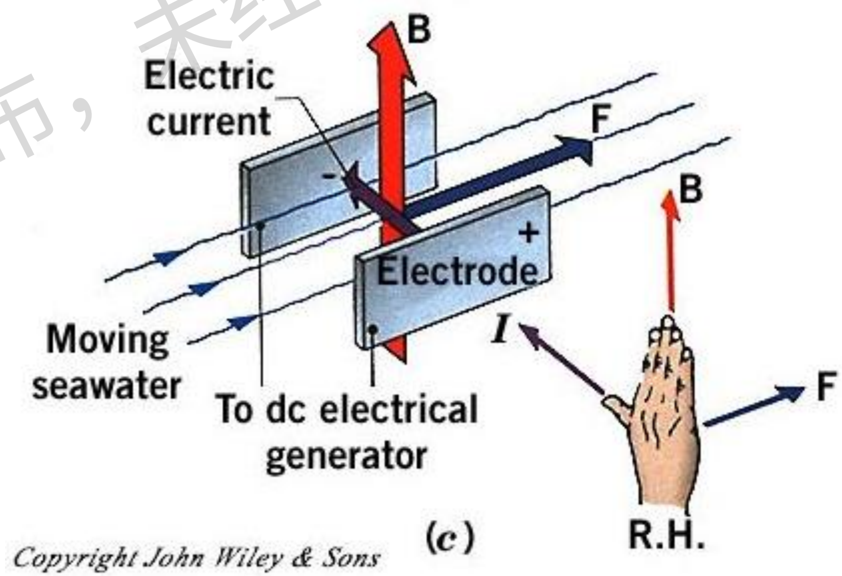
❖Present and future of worldwide marine electric propulsion

►2010’s

- ✓ DC gird
  - Optimal operation of Gen-set
  - Higher efficiency thanks to reduced power conversion
- ✓ More electrification
  - Hydraulic, pneumatic → Electric

►2020’s ~

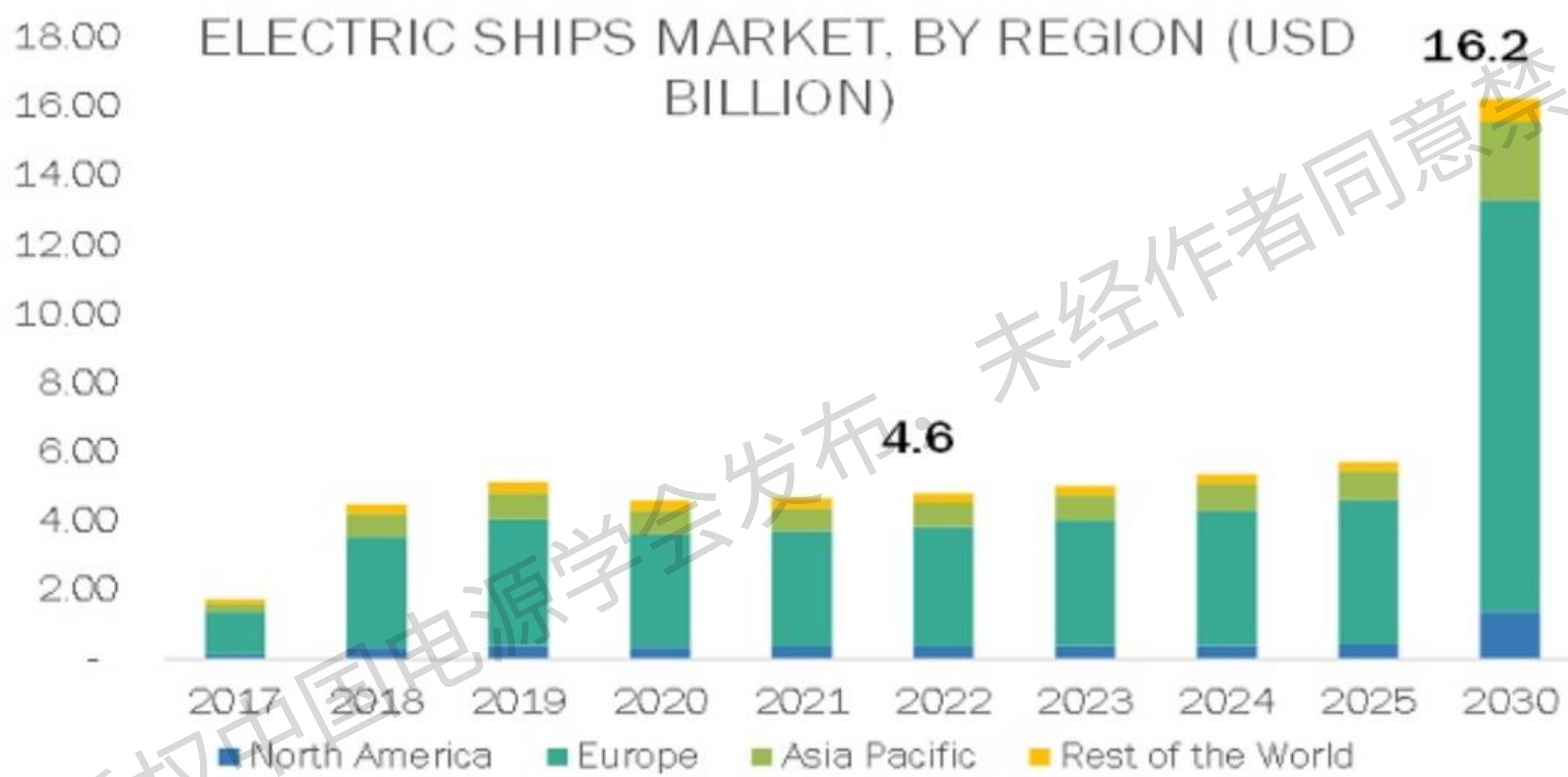
- ✓ Green hydrogen
  - Hydrogen fired engine
  - Fuel cell
- ✓ Propeller-less propulsion
  - Superconductive magnet based linear propulsion



Magneto Hydro Dynamics

Electric Propulsion Ship

❖ Market volume forecast



https://www.marketsandmarkets.com/Market-Reports/electric-ships-market-167955093.html?gclid=CjwKCAjw_JuGBhBkEiwA1xmbRfzVE8m8tgGOWwE-9BwU33iYFxrAYSLcWEdW7ggJlBLiKV4ngpnn2hoC_bsQAvD_BwE

Electric Propulsion Ship

❖Total cost for ownership

- ►Before 2000': Ship cost > 3 times of fuel cost
- ►After 2010: Ship cost < fuel cost
- ►2020's: Mandatory use of ULSFO, MGO → 50 % more fuel cost

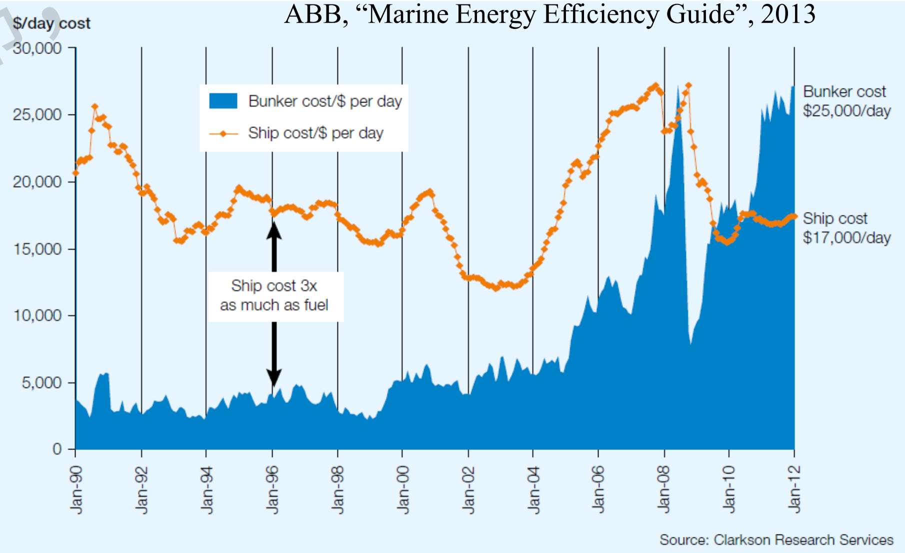
❖Cost for 1 kWh by fuel cost only

* ULSFO : Ultra Low Sulphur Fuel Oil, MGO : Marine Gas Oil

- ►1990's: 2 cent/kWh, 2017: 9 cent/kWh, 2020's: 13 cent/kWh

❖IMO regulation

- ►CO^2 emission from marine industry :
  - ✓ 3.3 % @ 2007 → 12~18 % @2050
- ►Target of GHG emission reduction compared to 2008
  - ✓ ~2014: 5%,
  - ✓ ~2019:10%,
  - ✓ ~2024: 20%
  - ✓ ~2030: 40%



ABB, "Marine Energy Efficiency Guide", 2013

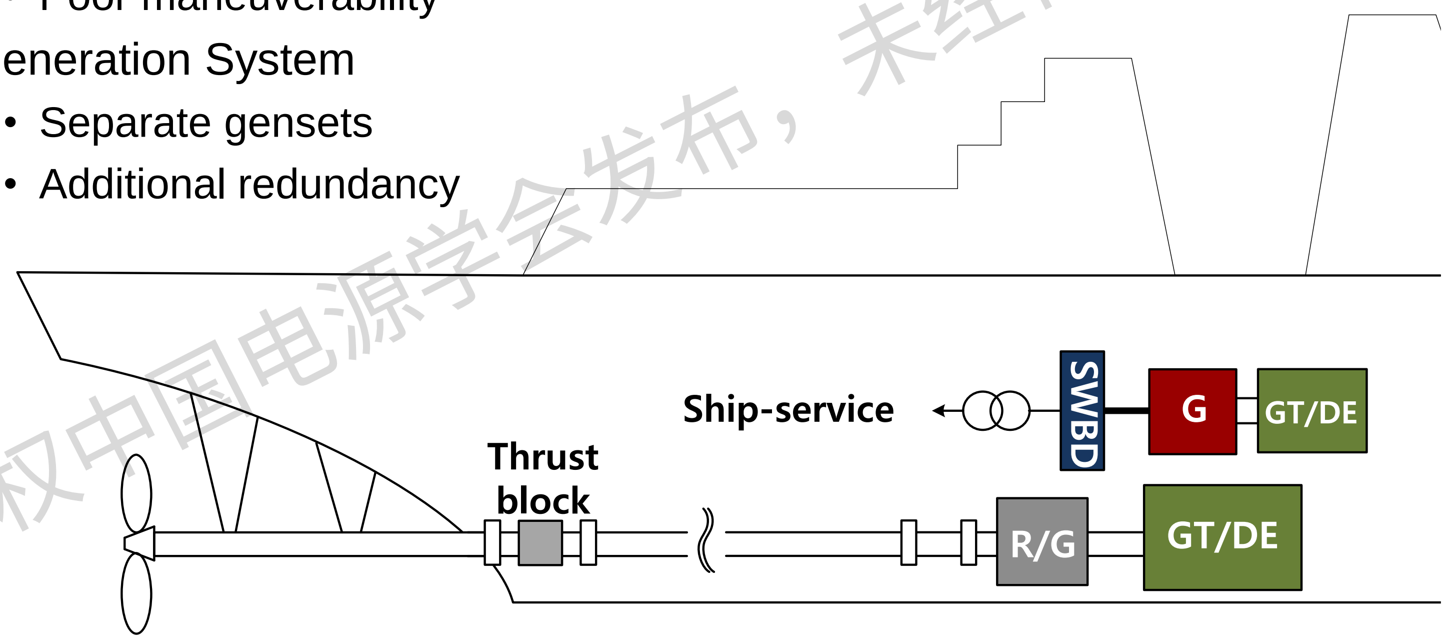
Comparison : Electric Propulsion Ship vs Mechanical Propulsion Ship

Comparison: Electric vs Mechanical

❖Structural comparison

►Conventional Mechanical Propulsion

- ✓ Propulsion System
  - Controlled Pitch Propeller + Long Shaft + Reduction Gear + Engine/Turbine
  - Regular maintenance, noise and vibration
  - Slow dynamics
  - Poor maneuverability
- ✓ Generation System
  - Separate gensets
  - Additional redundancy



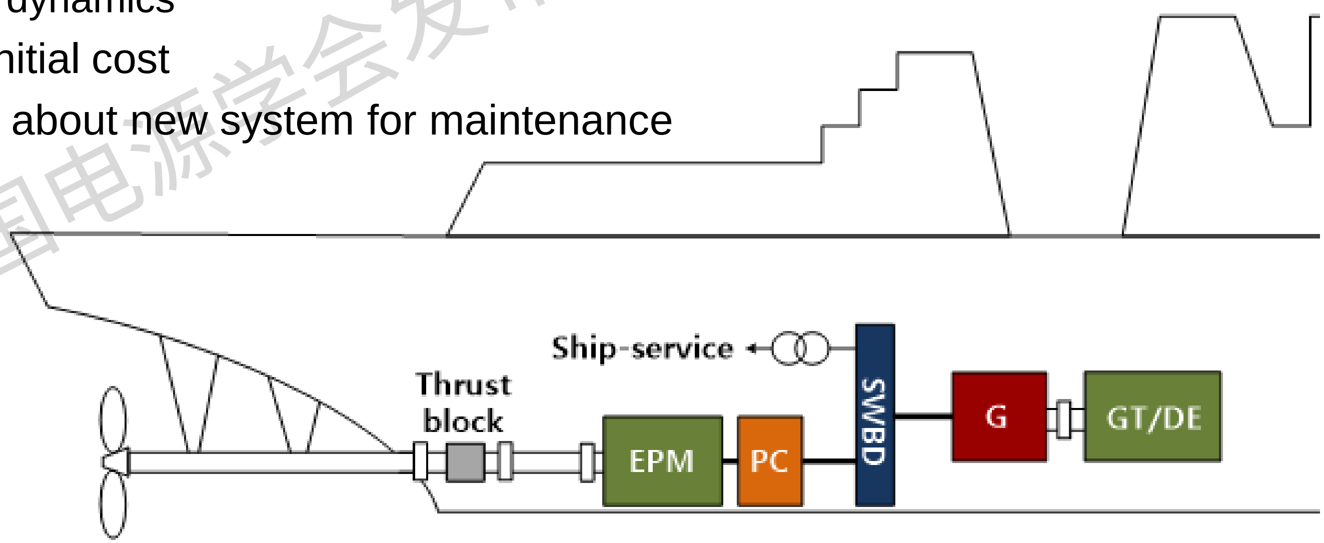
Comparison: Electric vs Mechanical

❖ Structural comparison

► Electric Propulsion

✓ Integrated Power System (IPS)

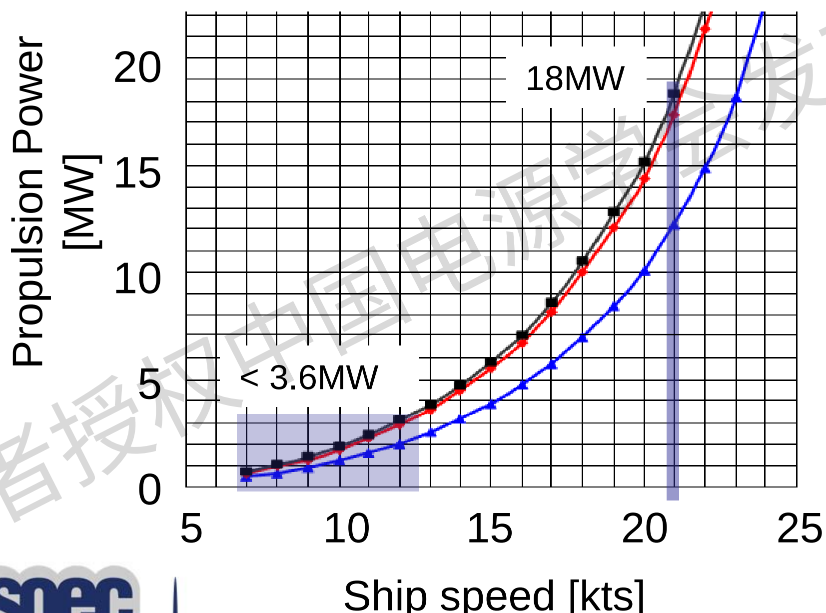
- Gensets for both propulsion and electricity
  - » Reduced redundancy
  - » Increased load factor → Higher fuel efficiency
- Simple Fixed Pitch Propeller + Shaft + Motor + Inverter to SWBD
  - » Wide speed-torque range → reverse thrust, regeneration
  - » Free from regular maintenance, reduced noise & vibration
  - » Fast dynamics
- Higher initial cost
- Training about new system for maintenance

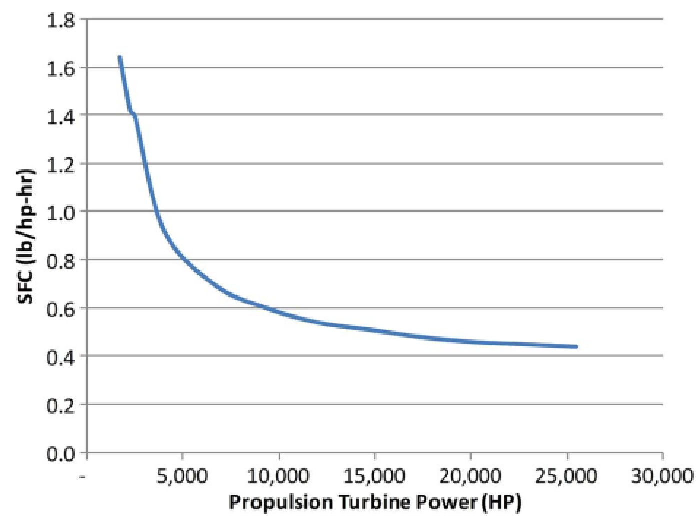


Comparison: Electric vs Mechanical

❖ Problem of the mechanical propulsion

- ►Poor load factor
  - ✓ For maximum ship speed; 21 kts → Rated power; 18 MW
  - ✓ For cursing speed; 15 kts → Less than half power; 6 MW
    - • 80% of operation time < 15kts; 33% load factor
    - • 55% of operation time < 12kts; 20% load factor
- ►Reduced fuel economy, Increasing malfunctioning & maintenance





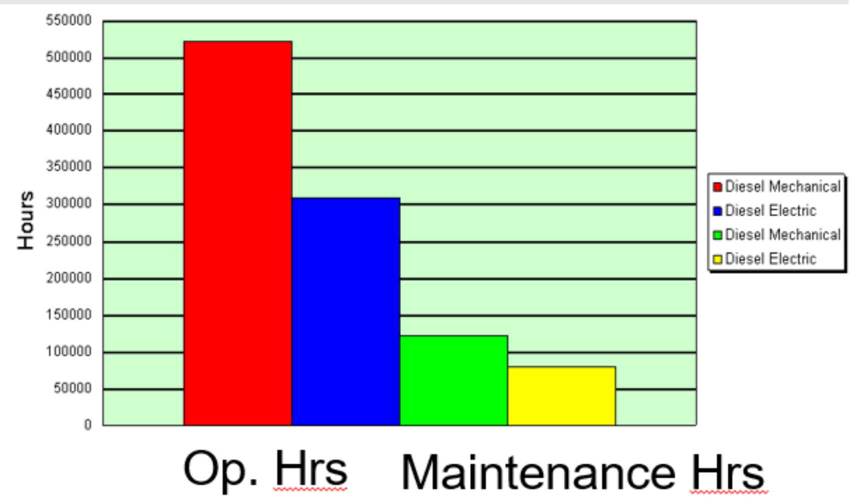
“Hybrid Electric Drive for Naval Combatants,” D. Alexander, *Proceeding of the IEEE*, vol. 103, No. 12, Dec. 2015.

Comparison: Electric vs Mechanical

❖ Advantages of electric propulsion

- ▶ Reduced maintenance, crew, operation cost
  - ✓ Numerous combination of generators → Enhancing load factor of engine
  - ✓ Less required component
    - No need of gearbox, clutch, CPP
- ▶ Reliability, flexibility and capability
- ▶ Supporting ever increasing electric loads
    - Accommodating future electric(pulse) loads
  - ✓ N-1 contingency (fail safe)
- ▶ Highly improved maneuverability
  - ✓ Dynamic positioning
  - ✓ Small turning angle
  - ✓ Much reduced crash stop distance

    15 ship lengths → 3~4 ship lengths



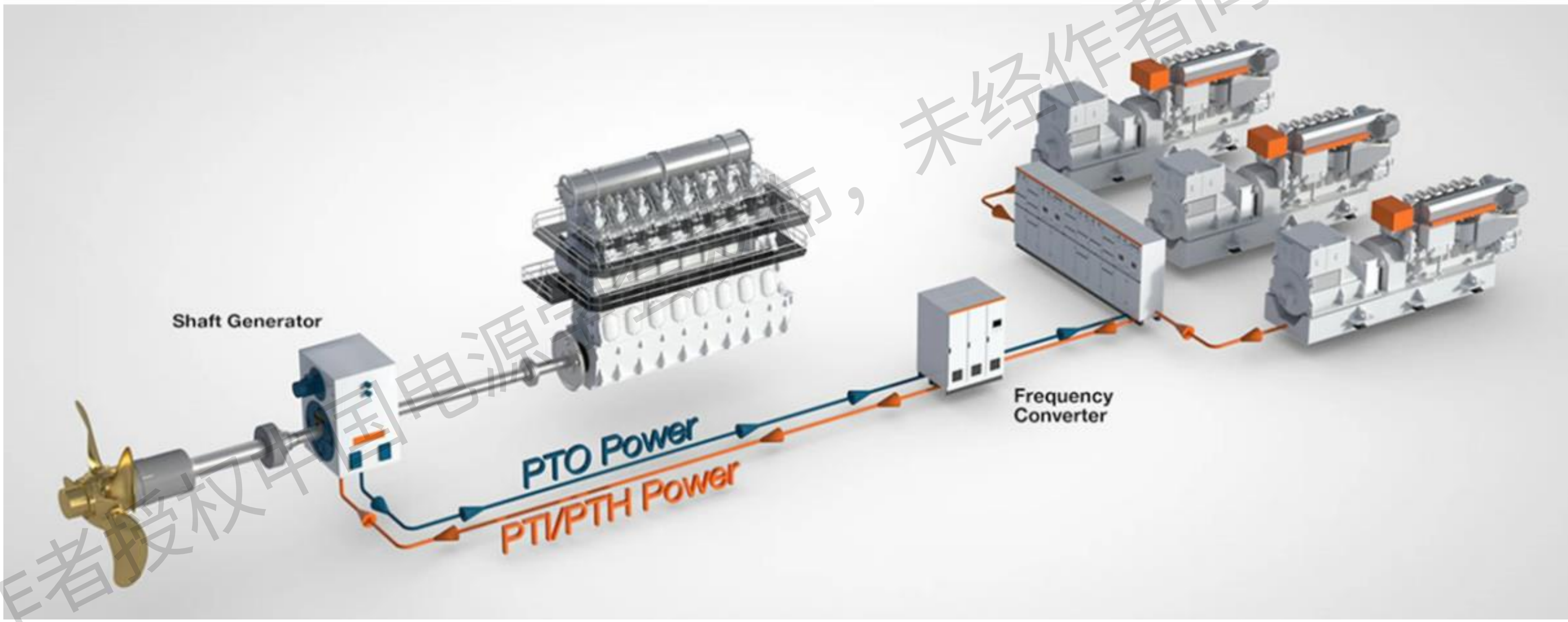
Courtesy of the US Navy

Case Study I :
Shaft Generator

Case Study I : Shaft Generator

❖Shaft generator

- ►Increasing load factor of main engine
  - ✓Saving fuels
- ►Electric propulsion at low speed



[Ref] https://www.wartsila.com/marine/products/ship-electrification-solutions/shaft-generato

Case Study I : Shaft Generator

❖Shaft generator

►Power Take Out(PTO)

✓ The electric machine on the shaft is working as a generator taking torque of main propulsion engine/gas turbine. And, by increasing load factor of main propulsion engine/gas turbine and reduced operation of generator engine, the fuel economy can be enhanced.

►Power Take In(PTI)

✓ The electric machine on the shaft is working as a motor for torque boosting for the main propulsion engine/gas turbine.

►Power Take Home(PTH)

✓ The electric machine on the shaft is working alone as a motor for the propulsion of the ship. → Electric propulsion

►STACOM operation

✓ Frequency converter can be used as STACOM for reactive power compensation to improve efficiency of ship generator.

[Ref] https://www.wartsila.com/marine/products/ship-electrification-solutions/shaft-generato

Case Study II :
DC Grid Electric Ship

Case Study II : DC Grid Ship

❖Whale watcher

- ►Ship for sightseeing: whale watcher at east sea of Korea
- ►L: 90 m, H:5.4 m, W:12.8 m
- ►2800 ton, 300 passengers
- ►Electric propulsion
- ►DC Grid → Variable engine speed

Case Study II : DC Grid Ship

❖Whale watcher

- ►Basic specification
  - ✓16 kts
  - ✓3.6 MW generation capacity
    - Two wound rotor synchronous generators(WRSG)
  - ✓1 MWh Li-ion Battery
    - 30 min battery operation
  - ✓1100 V DC link voltage
  - ✓2.6 MW propulsion
    - Two induction motors
- ►Key power electronics technologies
  - ✓Active Front End(AFE)
    - PWM boost converter between WRSG and DC grid
      - » Sensorless control, no filters, variable speed operation of gensets
  - ✓Sensorless control of propulsion motors
  - ✓Solid state circuit breaker in DC grid

Thank you

Seoul national university
Power Electronics
Center
SPEC