May 2023

Combined Naval Event (CNE) Conference

AFFORDABLE, AVAILABLE AND AUTONOMOUS AMPS

Lower Cost, High Power Architectures and Autonomous Power System Considerations

Marine Power Systems Selection

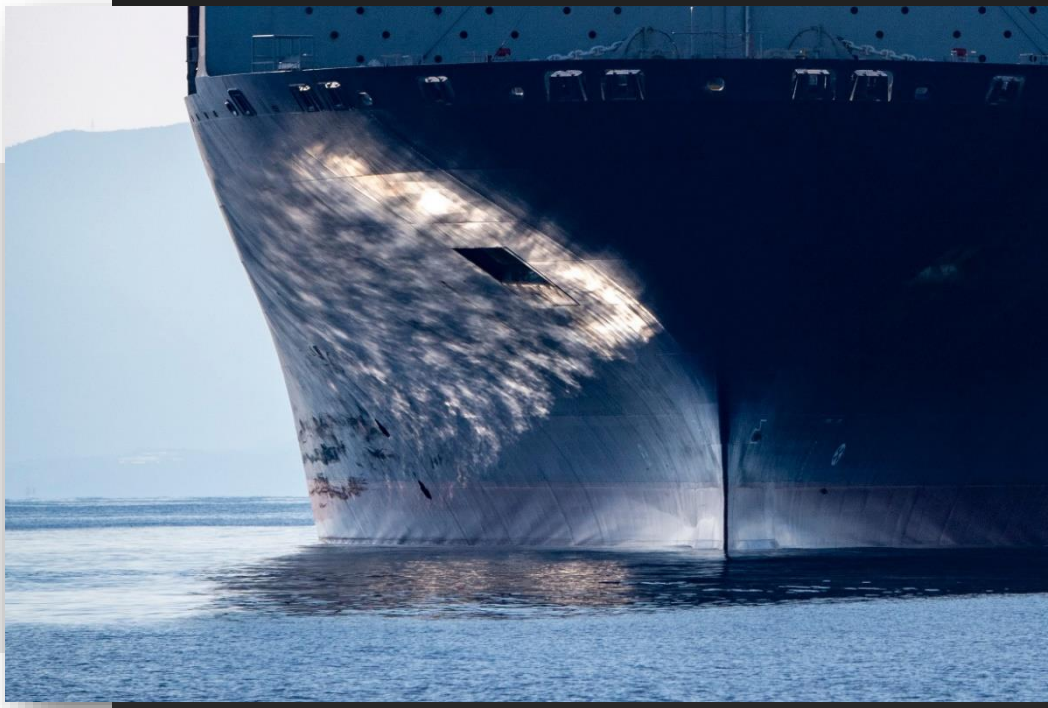
Commercial platforms: electrification at an increasing rate

- Flexibility and future-proofing demand for electrical power
- From 2,000 tonne offshore support vessels to 250,000 tonne cruise ships
- Electric is flexible, more green and increasingly demanded by charterers.

Naval platforms: real and perceived challenges

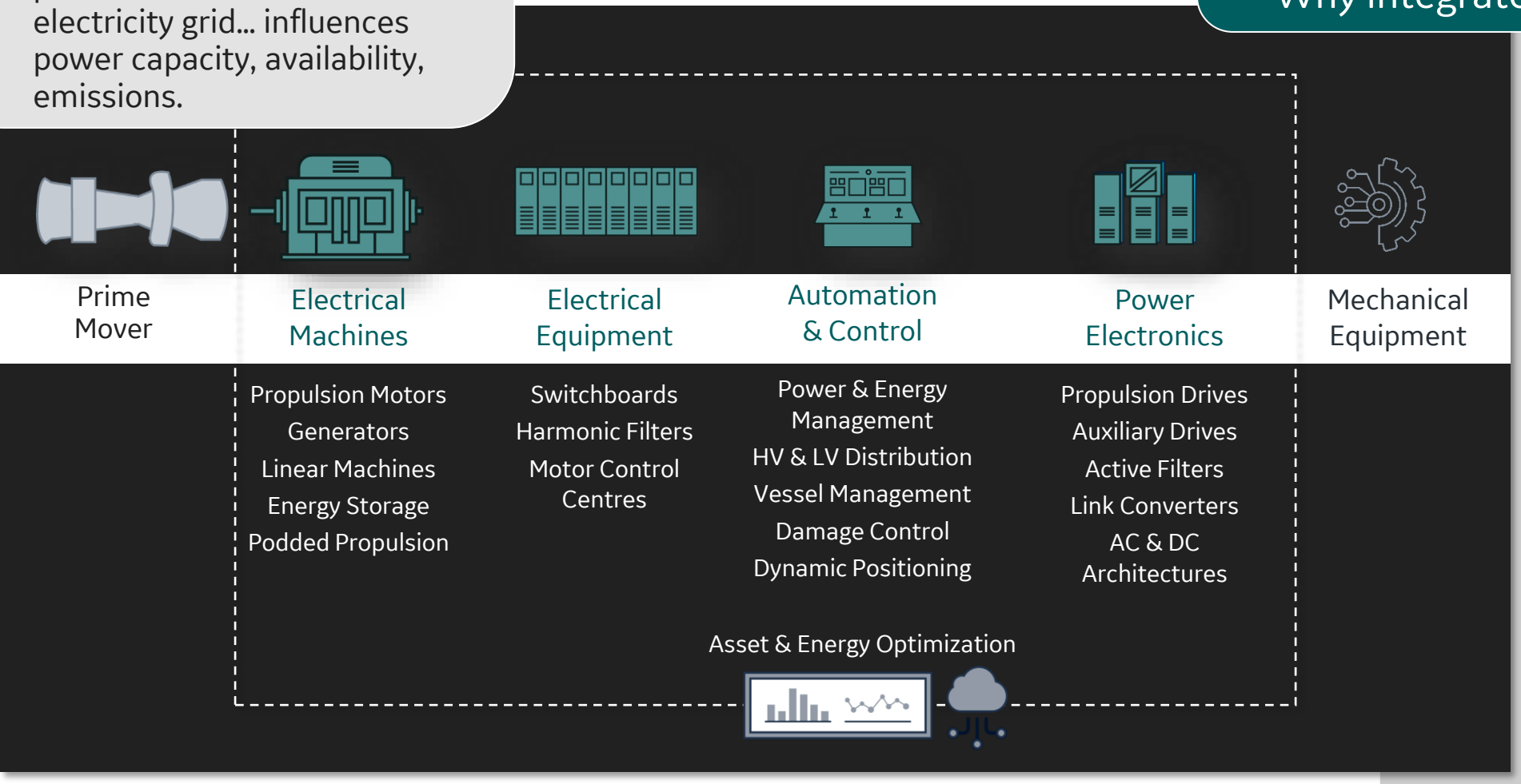
1. Prime mover options - gas turbines (GT) and/or recip engines impact integrated system
2. Vessel size – **perception that electric is for large, high voltage ships** only – **not** an issue in commercial marine sector

Warship or commercial, there is always a cost, capability and future-use trade-off for vessel technology choices



GE's Ship's Electric Grid

Prime mover choice, like power stations behind the land electricity grid… influences power capacity, availability, emissions.



Why integrated full electric power (IFEP)?

Increased power for **electrically-enabled missions**

Brings together future combat, platform and autonomous capabilities

Holistic **energy management**

Integrate emerging, **cleaner energy sources**

Aligns crew modern skills in wider industry (inc software, controls, electronics)

Lower maintenance

1. ‘Commercial’ configuration, cost-effective (e.g. 2,000-8,000 GT)

Commercial, but high-performance specification

Recip engines, no gas turbines

AC or DC low voltage architectures

Thruster power for transit and loiter modes

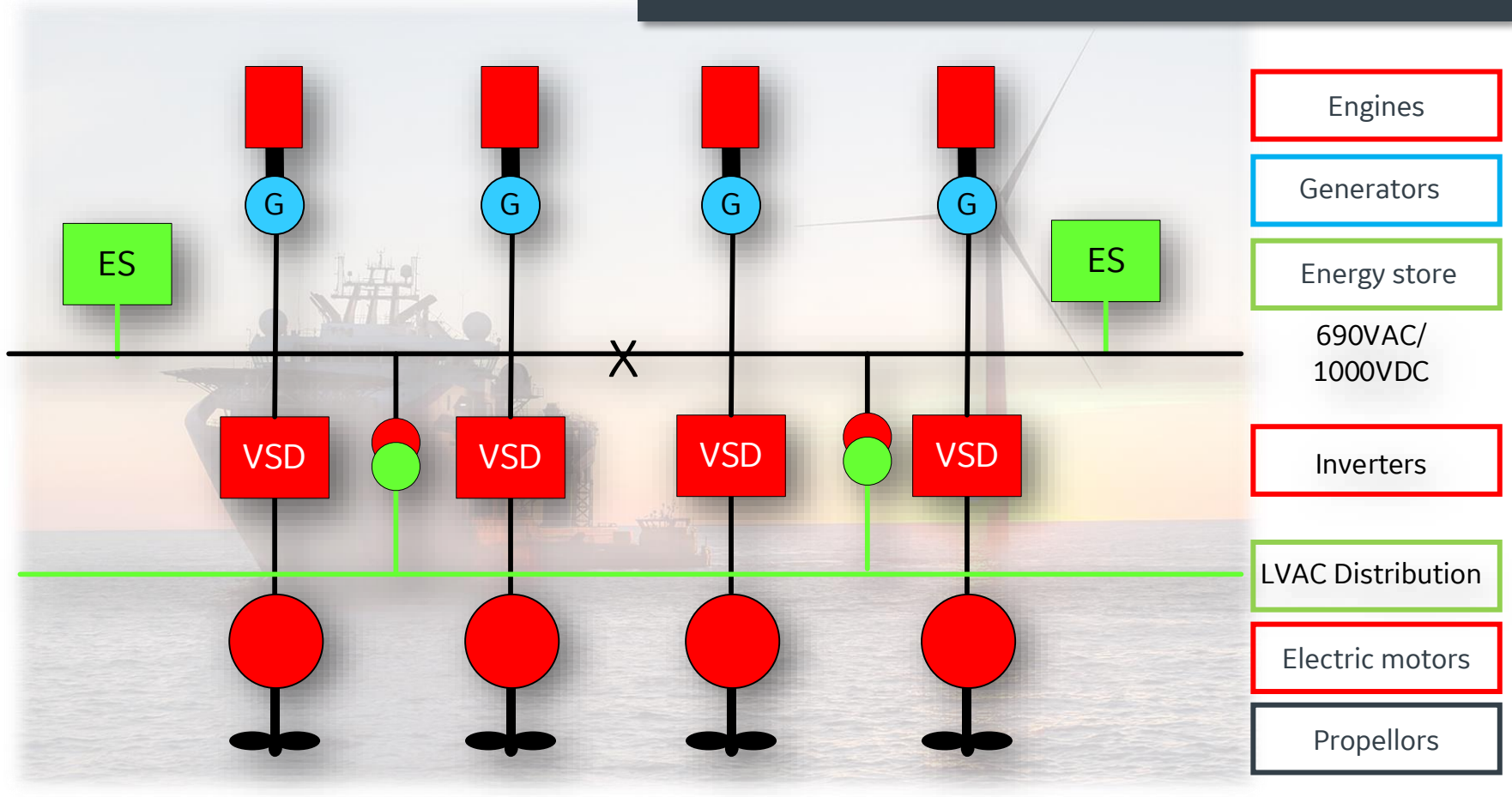
‘Bread and butter’, lower cost

Compact footprint

Latest incorporate BESS

Shift to cleaner fuel-capable prime movers (methanol, etc)

E.g. offshore energy support vessel



IFEP: integrated, full-electric power and propulsion
BESS: battery energy storage system

2. Naval equivalent: low-cost option?

Similar configuration

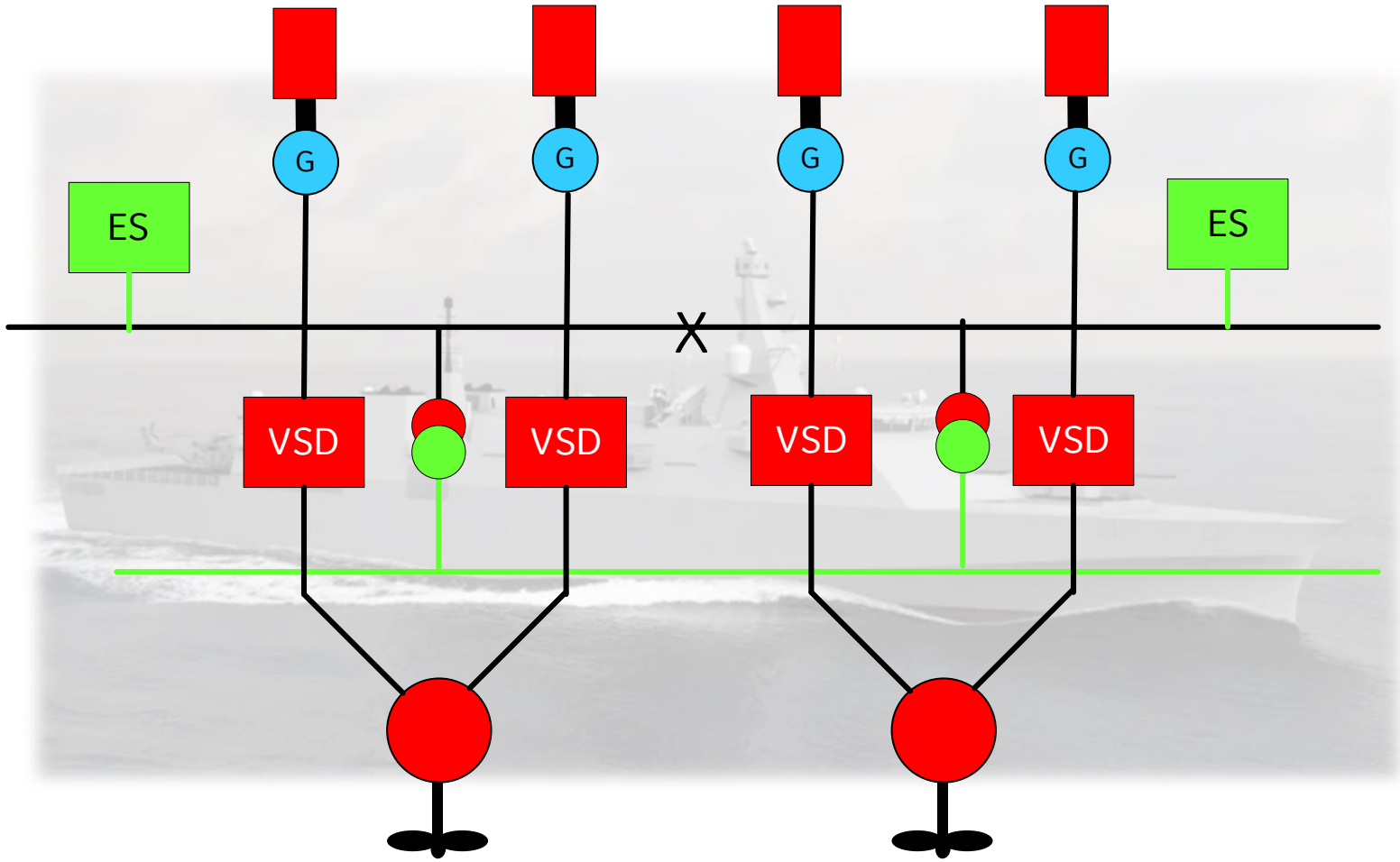
Recip engines, no GTs

Two shafts

Need more power?

- Increase recip (genset) size
- Reduce speed slightly
- Add BESS for peak loads
- Fit a GT… (see next)

E.g. naval support and multi-role



690VAC/
1000VDC

Inverters

LVAC
Distribution

LOW VOLTAGE ELECTRIC SHIP

3. Naval ‘hybrids’ : Low power IFEP and boost GT

Gas turbine(s) for ‘sprint’ speed. One or two, depending on cost and space, plus gearbox(es)

Additional footprint, power loss on a single failure can be >>50%

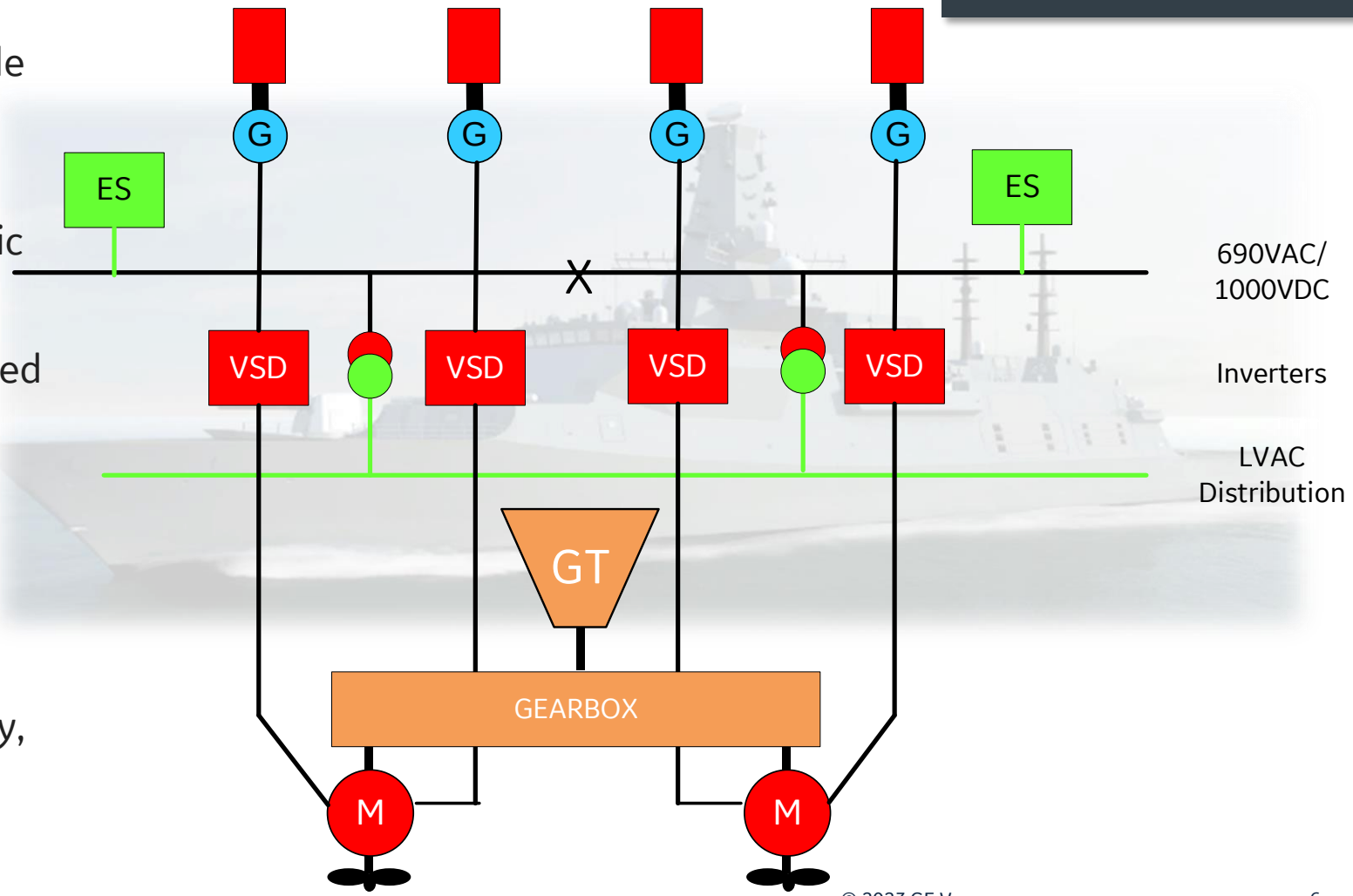
Not IFEP configuration, so limits power sharing and flexibility benefits from electric grid

Compact LV drives and distribution retained

GT selection can affect recip engine selection: size, cost, diesel cruise compromise, lowers installed electric capacity

Does a mothership with fast UAVs really need this inflexible, large, expensive, heavy, mechanical 25-30kt boost capability? Which is infrequently used

E.g. naval frigate



Power and propulsion tailored for Autonomy

Lean-manned mothership
Higher electrical power capability
Extensive mission systems
Longer range and lifecycle
Fast Enough

USV/UUV/UAV
Fast, Lower cost, lower power demand
Varying mission duration and range
Attritable and retrievable

ELECTRIC, ENABLING AUTONOMY

4. Recip engines as generator prime movers: high power low cost Naval IFEP Mothership

All-recip IFEP configuration is lost opportunity in naval, it's where commercial world is

Example architecture here, cost-effective IFEP fits in 'mechanical' hull

Bigger engines may need MV, but can retain lower cost LV drives with simple transformer

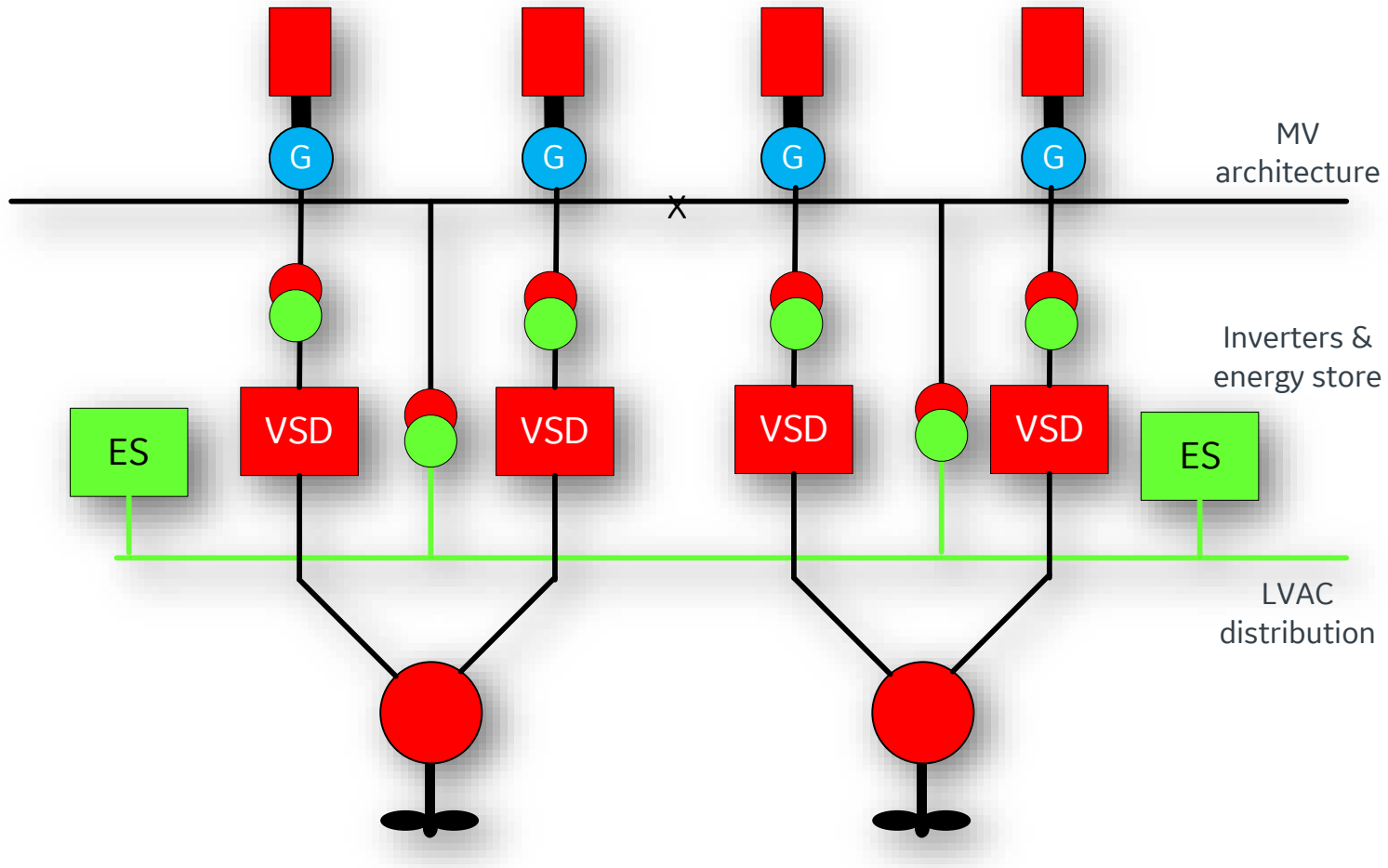
Simple architecture, low harmonics

Gearbox size/weights from mechanical solution are transferred to transformer

Electric-charging mothership, and 'modular' enabler

Optional Energy Storage

Breadth of applications, up to 8,000 tonnes / 25 knots



ELECTRIC MOTHERSHIP

Summary: lower cost electric mothership architecture

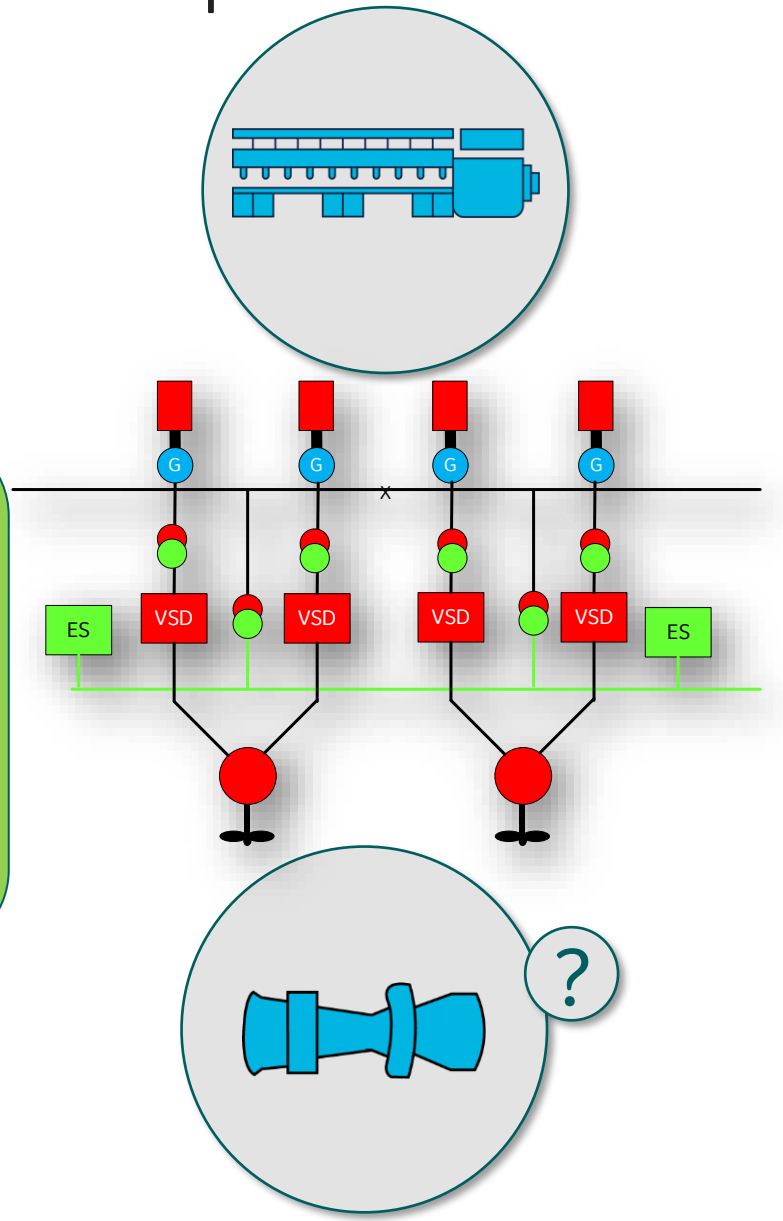
Retains Futureproof Electric ship provides flexibility of a grid to **distribute and share power**, for mission systems and propulsion

Similar to high-performance commercial vessels but with military 'hardening'

Simple, low-cost MV architecture, LV drives, transformers, low harmonics

Resilience and Flexibility is in the Mothership

Speed and Attritability is in the USVs



Adapting lower-cost IFEP for lean / unmanned future motherships

Power and energy scenario: what happens if something breaks? or burns out? or your only fix is down a satellite link?

Need:

To Reduce Dependence on People for maintenance and action damage recovery

- More auto/remote configurability
- More sharing and rerouting of power
- Fewer moving parts
- More electrically-connected items
- Fewer mechanically-connected items
- Graceful degradation, reconfigurability, safe modes, limp home
- Needed for Lean Manning First, enabler for Autonomy

How can we Adapt Mothership IFEP to Reduce Crew, Training, Recruitment, Harm?

ELECTRIC MOTHERSHIP

Electric Ship Building Blocks, Reconnected for Availability

Most standard, low cost generators and motors are AC machines

Most electric drives have similar building blocks

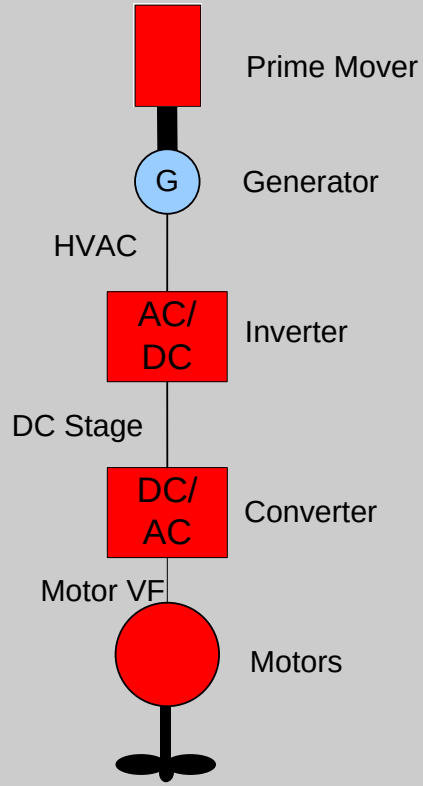
- AC to DC inverter, DC link, DC/AC convertor, AC motor
- AC systems connect drives together at the AC bus level
- DC systems connect drives together at the DC stage

High availability systems sometimes combine motor variable-frequency outputs

Even if we have shared generators in IFEP system, the rest isn't shared.

If the inverter, convertor or motor fails, the whole function is lost

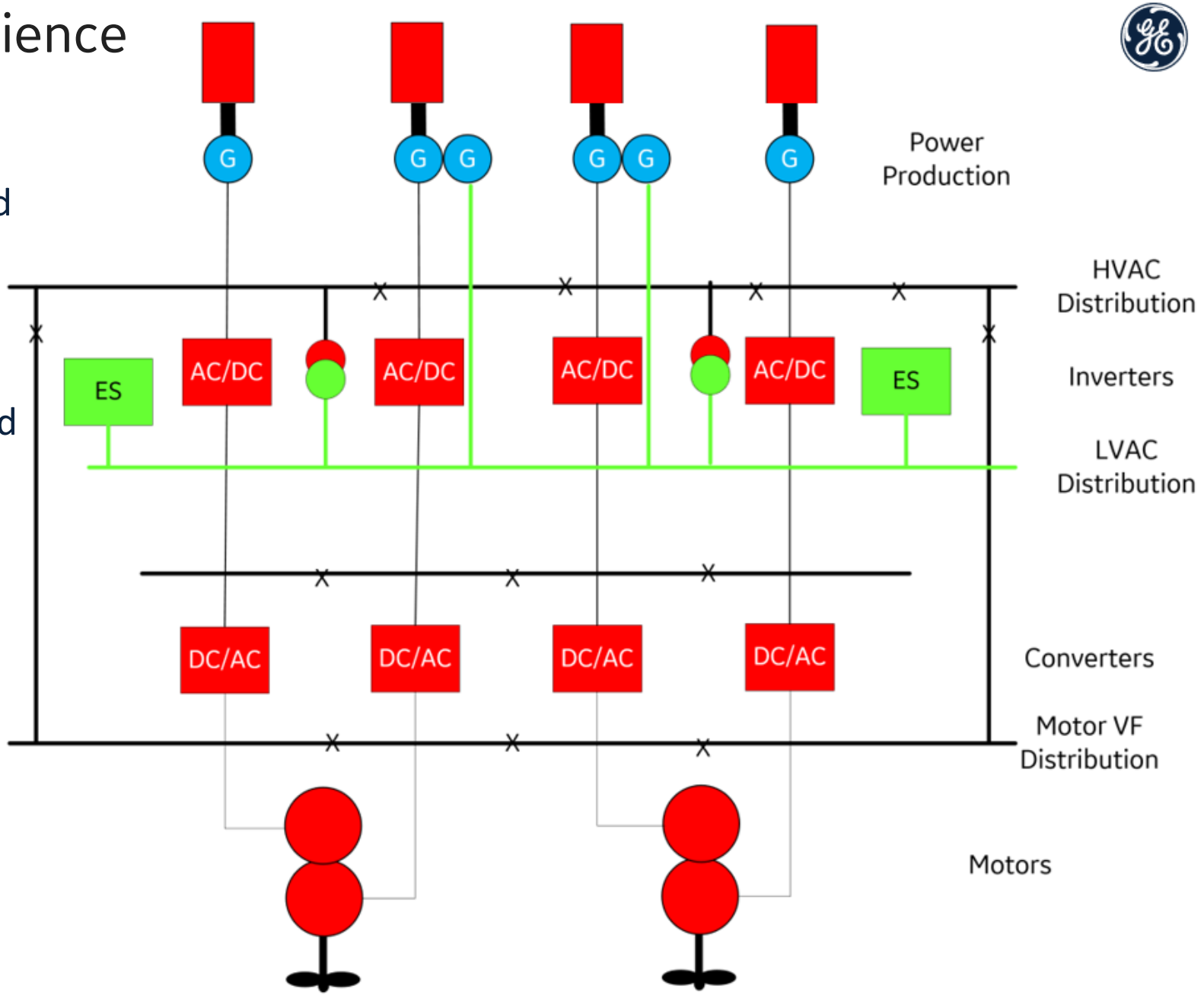
High availability, more-autonomous systems will share these existing system components better: **Matrix architectures**



MATRIX RESILIENCE

Matrix Architecture Resilience

- Combine generation, services and propulsion converters with distribution at AC, DC and variable AC
- IFEP gives any generators any load
- Matrix gives any inverter any convertor, any motor
- Failure of any red component is now independent, not linked.
- Solid-state, remote rerouting of components…
- …“Electronic swaps by software” vs “physical swaps by crew”



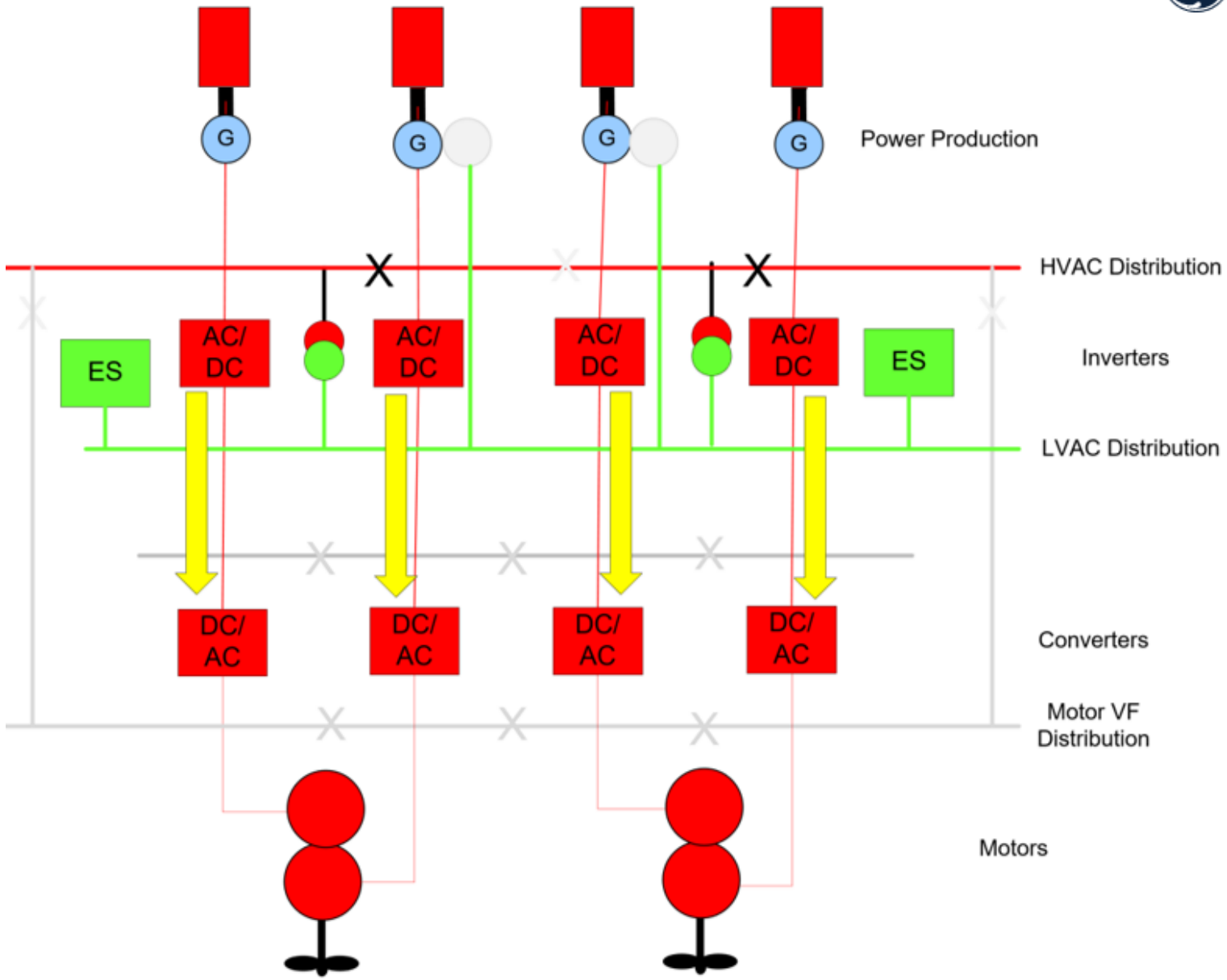
MATRIX RESILIENCE

From Classic IFEP Buddy Operating Mode...

With energy store

2 ship-service transformers feed LV bus

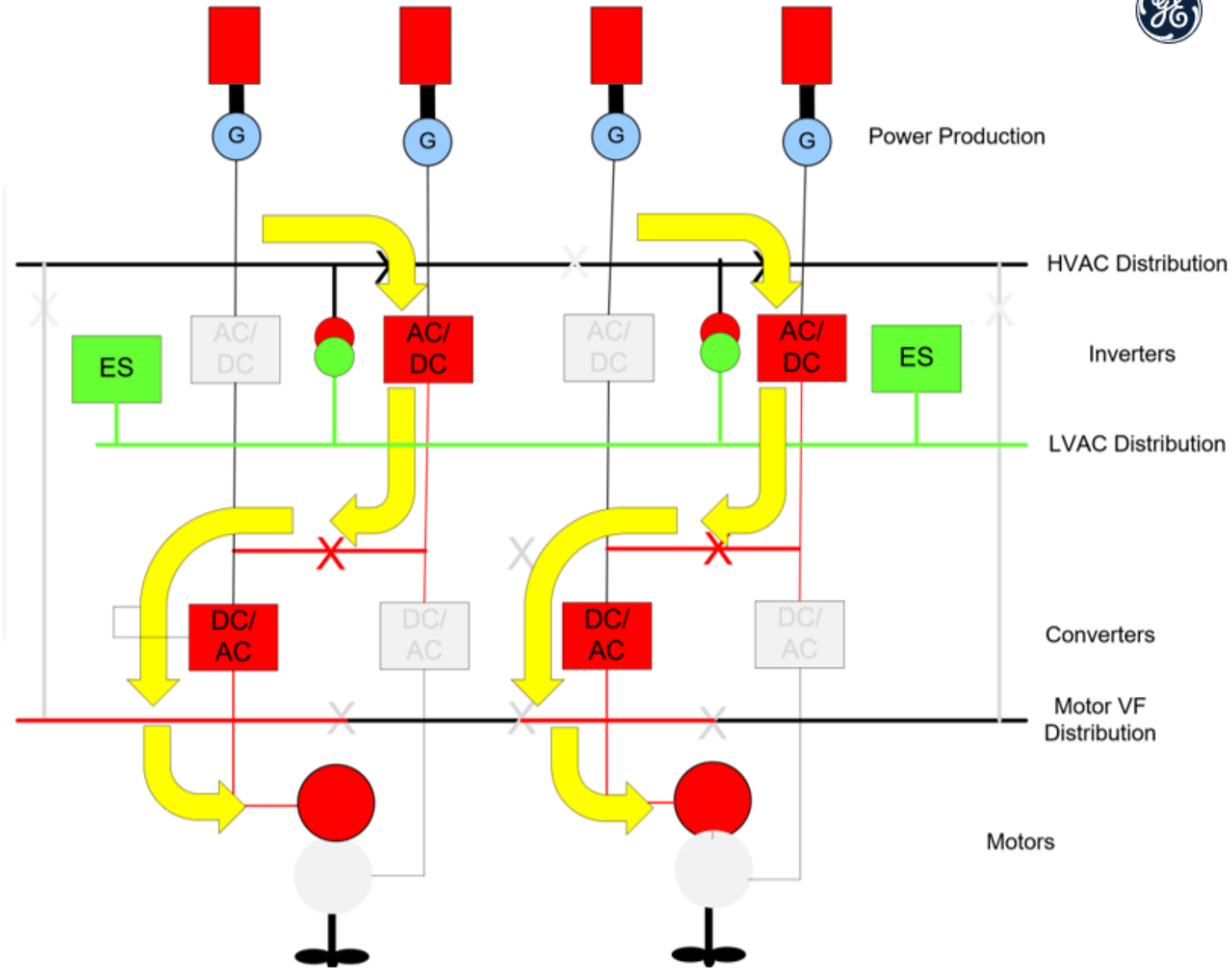
Inverter tied to buddy convertor, tied to buddy motor



MATRIX RESILIENCE

To Full Matrix IFEP Sister Operating Mode

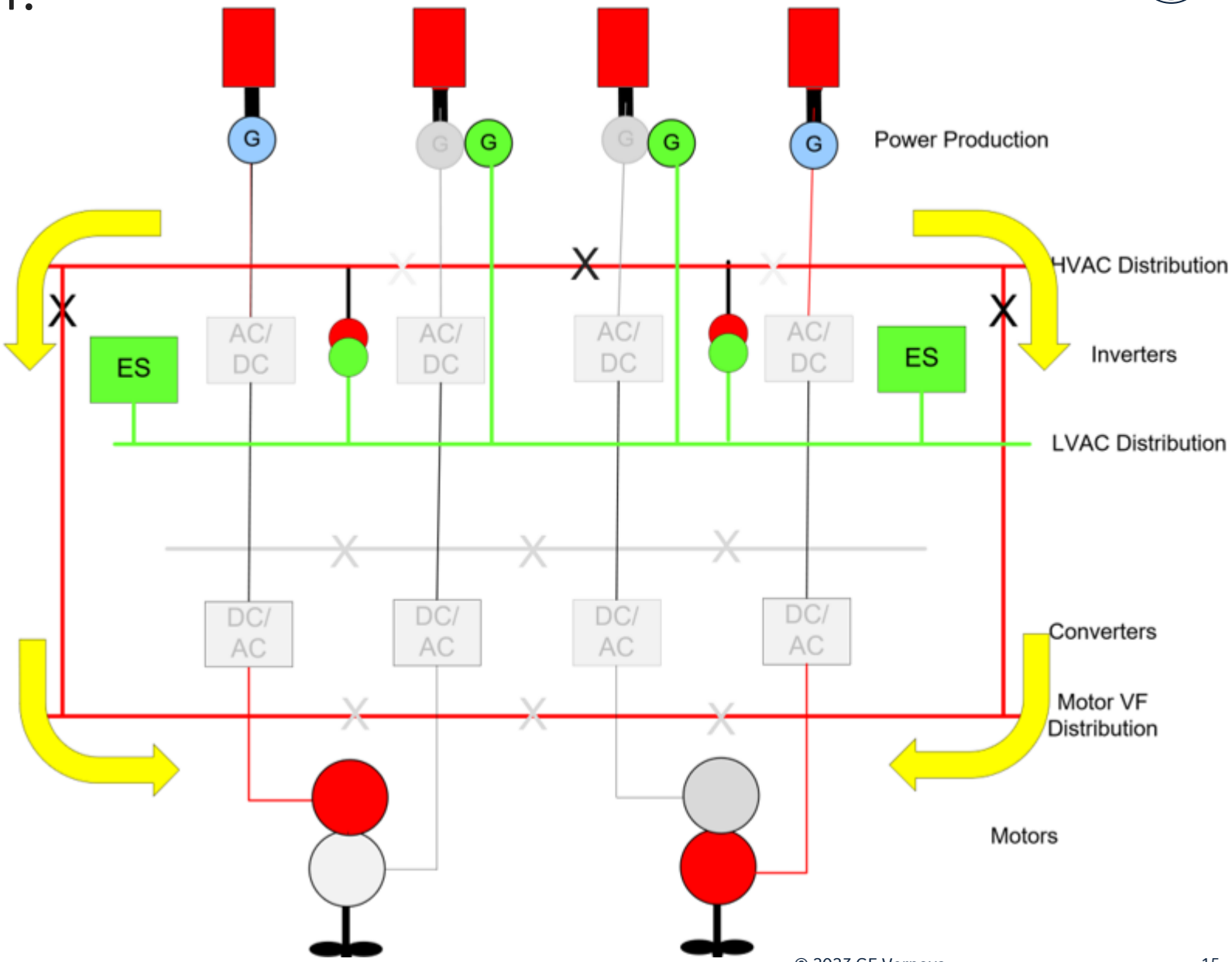
- 2 ship-service transformers feed LV bus
- Inverter switched to sister converter, not its own
- Bypassing inverter or convertor failures
- Any inverter, any converter to any motor



MATRIX RESILIENCE

Converter-less operation?

- Get-home mode, low power
- AC machine to AC machine
- LV-fed from auxiliary winding or energy store
- Variable-speed engines to match frequency
- Propulsion-fed from soft start LV bus/AVR



MATRIX RESILIENCE

Affordable, Available, Autonomous (Amps)

Electrical grids help to future-proof energy scale and decarbonization

Commercial marine deploys IFEP, from small to large ships.

'Barrier' to naval is installed power used for last 5 knots of speed

Lean Manned Mothership Concept using Autonomous USVs enables convergence with Affordable Commercial Approaches

Further Enhancements could include Matrix-connected for availability and resilience

Enabling further reductions in crew, remote and auto-configuration options

Ultimately leading to full autonomy IFEP

Lean, mean, green, converged marine