UH Energy Electric Vehicle Webinar Series

Electrification of Rail and Sea Transportation

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EVOLVE HOUSTON

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Agenda

- ➢ Introduction
- ➢ Electrification of Railways
  - ✓ METRO Rail
  - ✓ High Speed Rail
- ➢ Electrification of Ships
  - ✓ Commercial Fleet
  - ✓ Naval (Military) Fleet
- ➢ Summary

Electrification of Railways

Introduction to Railway Electrification

- Global market for railway line electrification was $12.38 billion in 2018, and will grow at ~4 % per year by 2022
- Global electric locomotive market size is projected to reach $7.85 billion in 2023
- A total market size of 4,000 units in 2012 and ~6,000 in 2020
- Rail traction can be segmented into three main sub-applications:
  - ✓ urban vehicles (trams and metros),
  - ✓ regional and commuters (mostly Electrical Multiple Units, or "EMUs"), and
  - ✓ high-speed trains (Power cars and EMUs).

Sources: https://www.prnewswire.com/news-releases/power-electronics-for-rail-applications-187727751.html
https://www.masstransitmag.com/rail/press-release/12408644/sci-verkehr-gmbh-new-study-railway-electrification-continues-to-grow-global-market-development-2018

Electric Locomotives – Houston Area

- **Houston METRORail** (since 2004)
  - ✓ 2nd most-traveled light rail system in Southern US
  - ✓ 37 Siemens S70 and 39 CAF USA vehicles
  - ✓ 600 V or 750 V DC overhead catenary
  - ✓ ~80 kW (110 hp) traction motor – per tram

- **Texas Central Railway** (planned 2026)
  - ✓ High speed trains
  - ✓ Based on the N700 Series Shinkansen
  - ✓ Up to 205 mph → 'Bullet Train'
  - ✓ Houston to Dallas in ~90 mins
  - ✓ All electric system, with steel wheels

Sources: https://en.wikipedia.org/wiki/METRORail ; https://en.wikipedia.org/wiki/CAF_Urbos_3_(Edinburgh)
https://www.texascentral.com/posts/texas-central-railroad-reaches-two-historic-milestones/

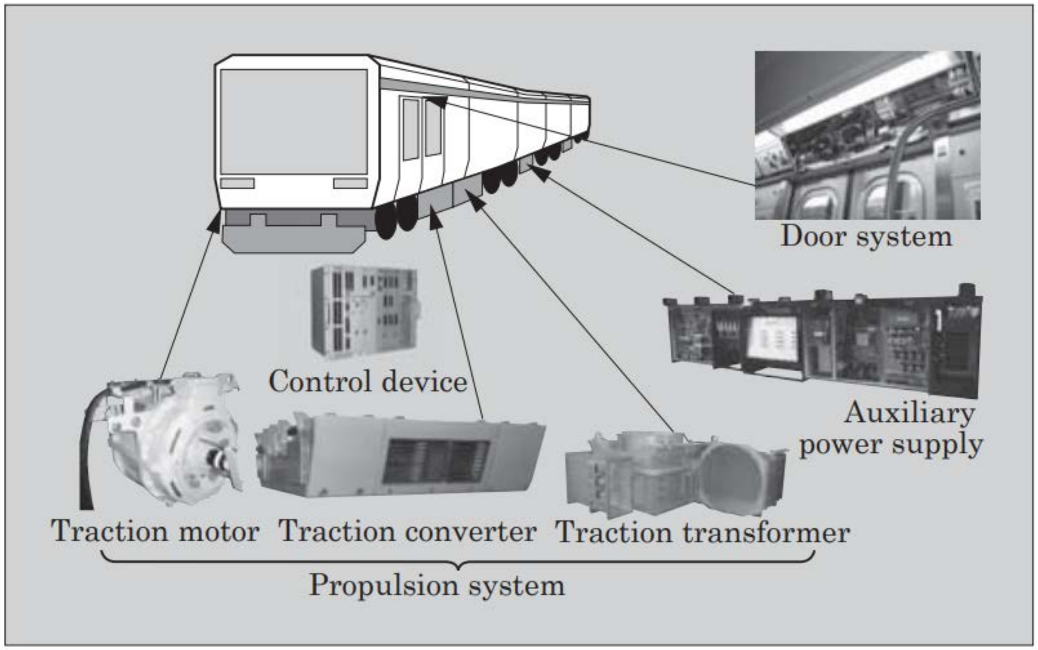
N700 Series Shinkansen – Main Specifications

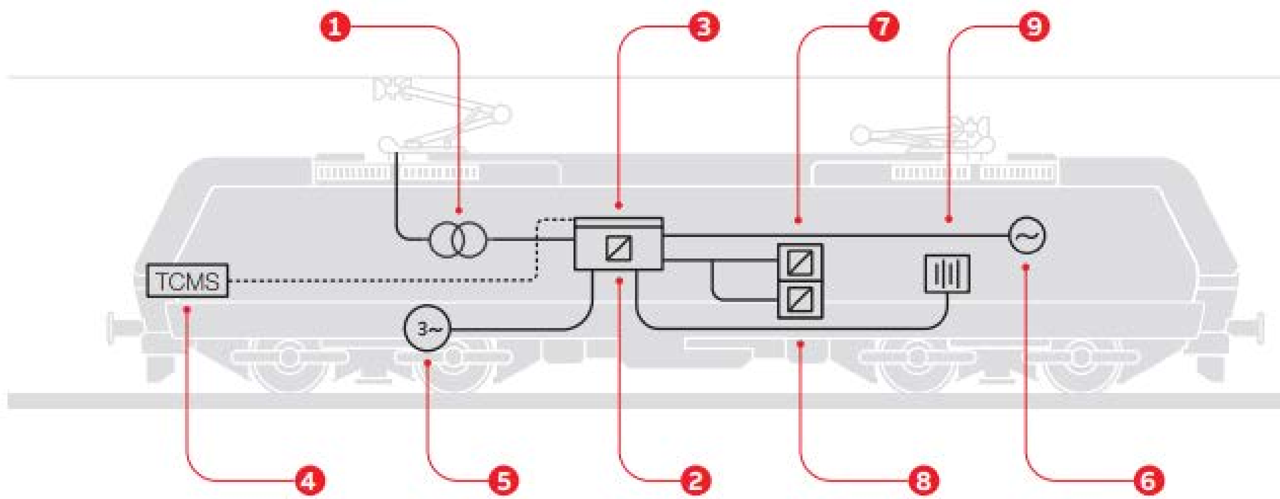
- 25 kV, 60 Hz AC input voltage; > 50 small motors for driving

Specifications		Series N700	Series 700
Formation		14M2T	12M4T
Unit configuration		4 cars per unit	(Same)
Seating capacity		1,323	(Same)
Maximum speed		Tokaido:270km/h, Sanyo :300km/h	Tokaido:270km/h, Sanyo :285km/h
Operating speed at curve (R2500m)		270km/h	250km/h
Starting acceleration		2.6km/h/s （Tokaido / Sanyo）	1.6km/h/s(Tokaido), 2.0km/h/s(Sanyo)
Weight (at capacity)		Approx. 700 tons	708 tons
Dimensions	Car length	Middle cars : 25,000mm Leading car : 27,350mm	(Same)
	Car width	3,360mm	3,380mm
	Car height	Front end of the leading car : 3,500mm Rear end of the leading car : 3,600mm Middle cars : 3,600mm	3,650mm
Total power output		17,080kW	13,200kW
Nose shape		Aero Double-wing (10.7m)	Aero Stream (9.2m)
Bogie structure		Bolsterless bogie	(Same)
Equipment for riding comfort		Advanced semi-active suspension system for all cars	Semi-active suspension system for seven cars
Body inclining system		Air spring mechanism (1"inclining)	-

Sources: http://www.railway-research.org/IMG/pdf/r.1.3.3.3.pdf

Electric Locomotives – Equipment

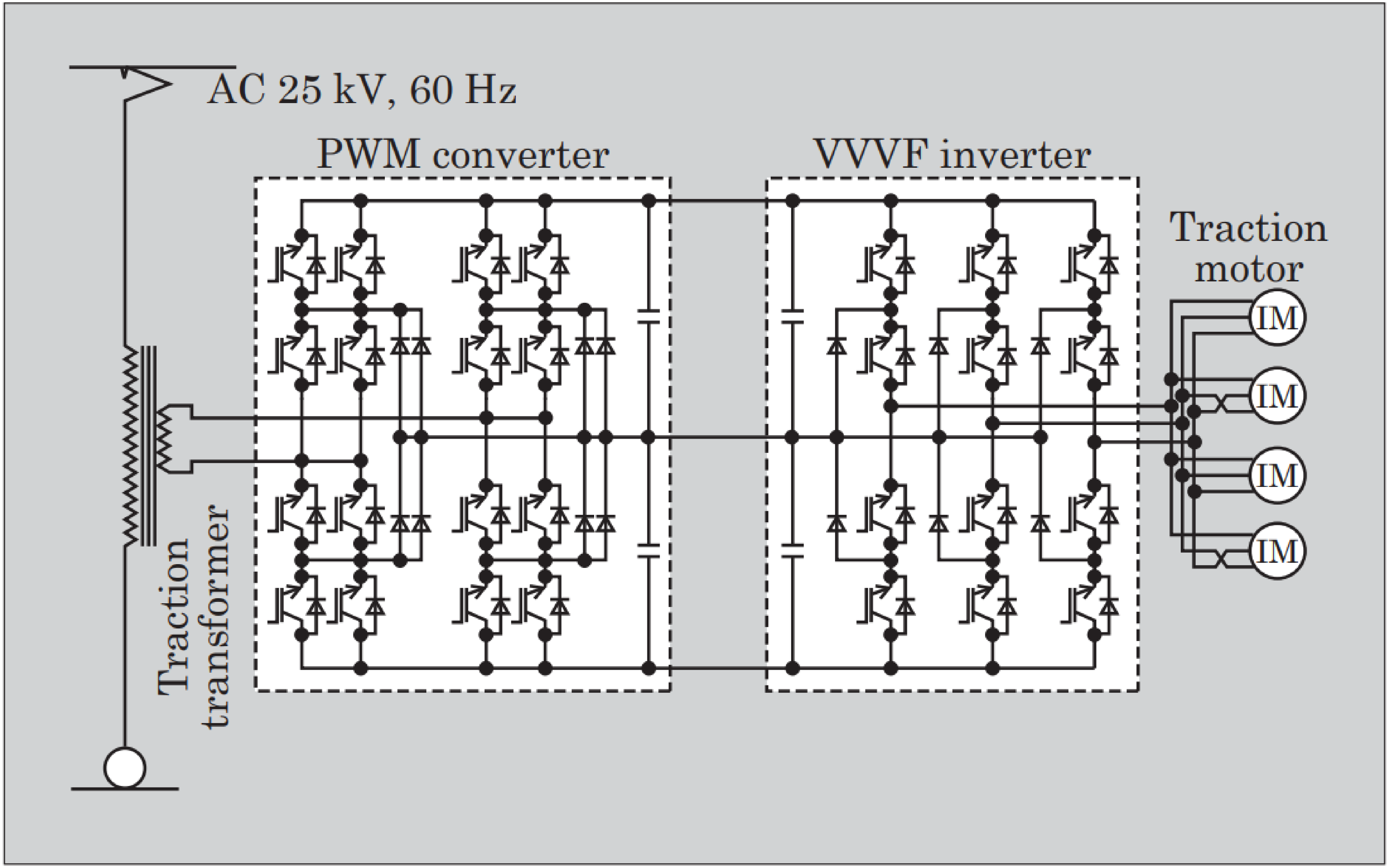




01 Traction transformer
02 Traction converter
03 Traction control
04 Train Control and Monitoring System
05 Traction motor
06 Diesel engine generator
07 Auxiliary converter
08 Battery charger
09 Energy storage

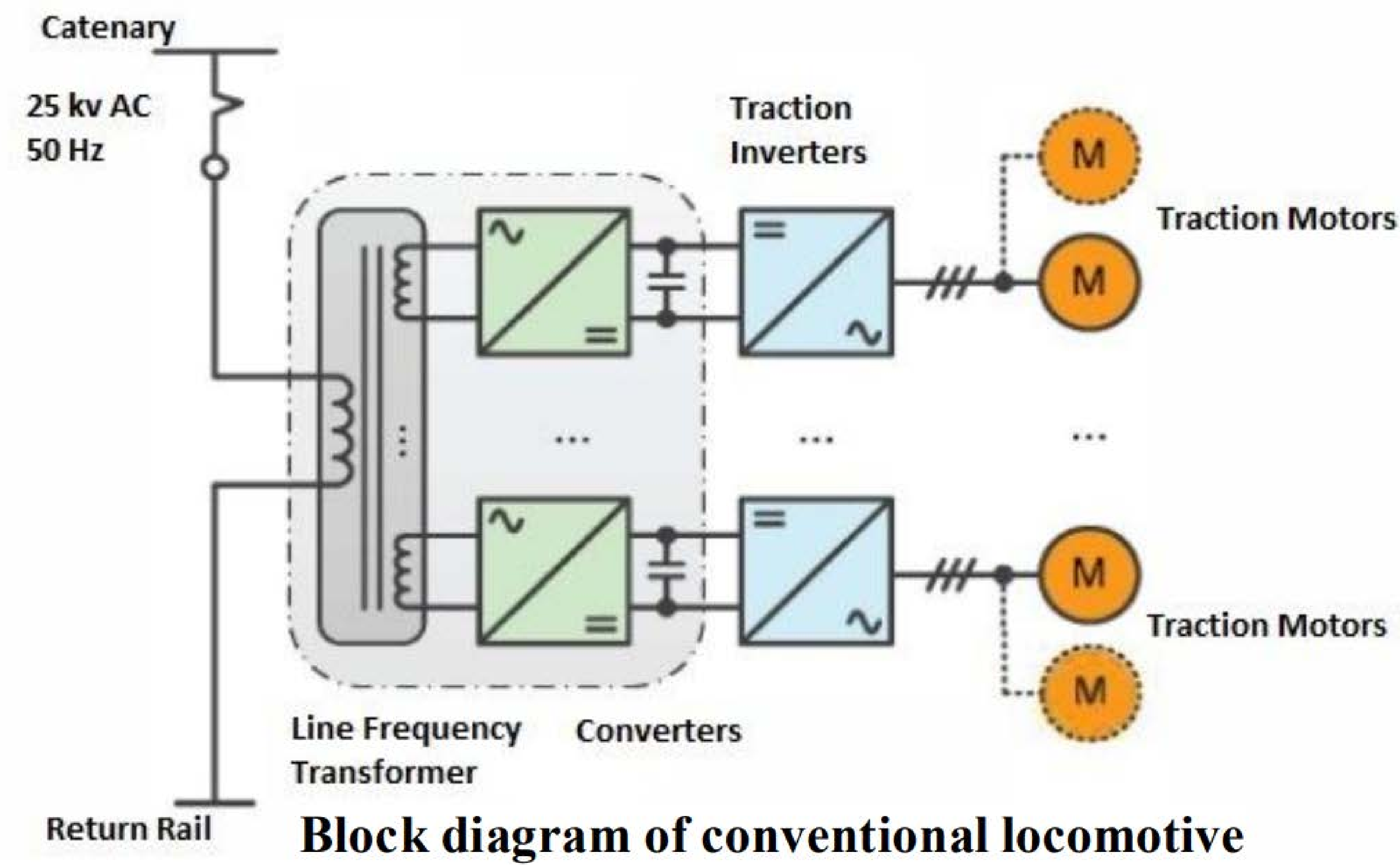
Sources: https://www.fujielectric.com/company/tech/pdf/58-04/FER-58-4-175-2012.pdf
https://library.e.abb.com/public/896cf517fcce4406b7a4facb6d6b7d0c/Traction_systems_high%20power_RevB_180916_web.pdf

N700 Traction Converter



Source: https://www.fujielectric.com/company/tech/pdf/58-04/FER-58-4-175-2012.pdf

Electric Locomotives – Architecture

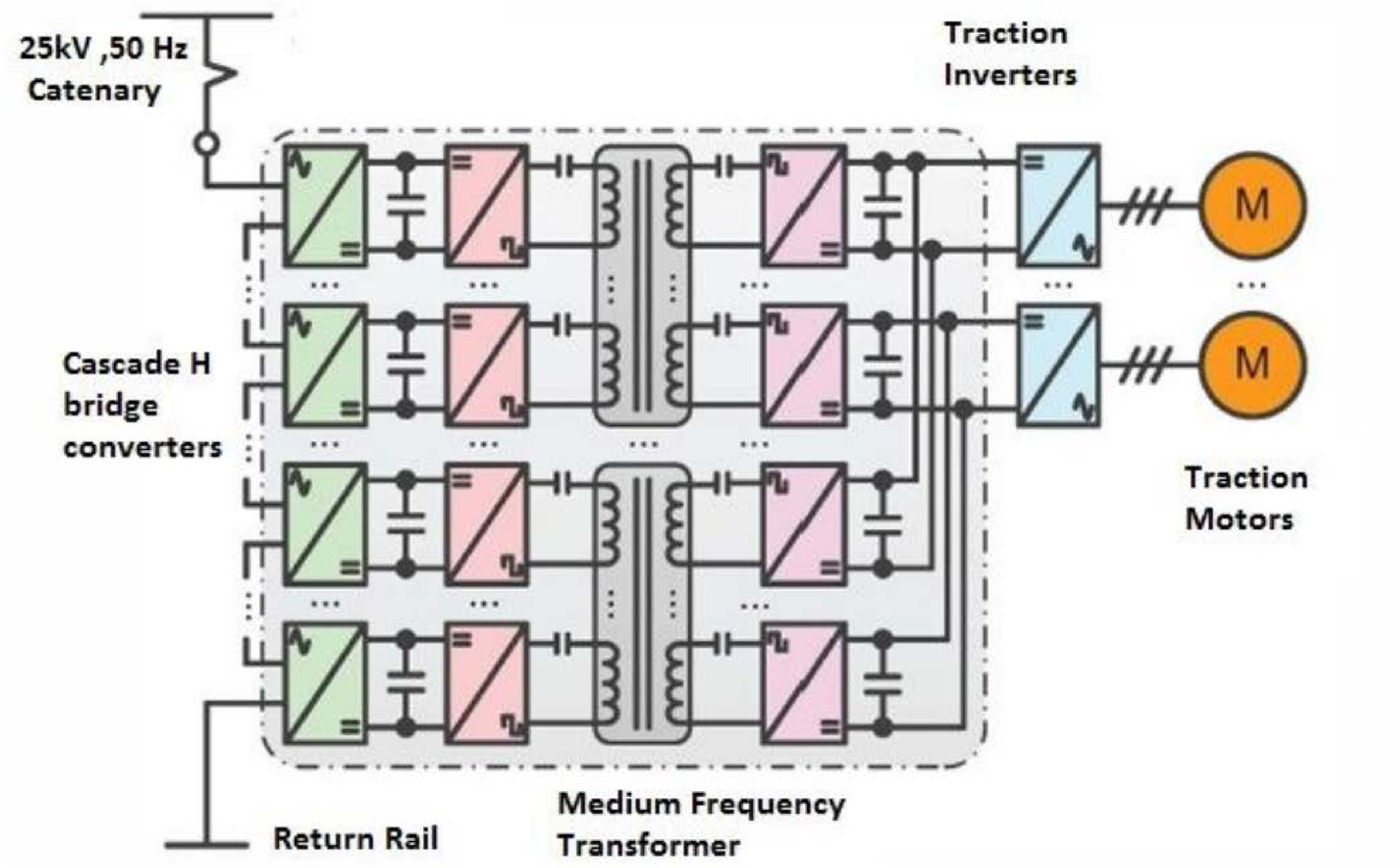


Block diagram of conventional locomotive

Sources: https://www.fujielectric.com/company/tech/pdf/58-04/FER-58-4-175-2012.pdf
http://www.digitalxplore.org/up_proc/pdf/387-153353684823-26.pdf

Electric Locomotives – Architecture

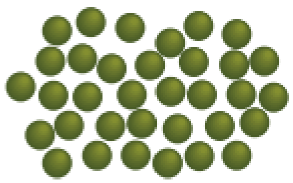
Power Electronic transformer (PET) with traction motors



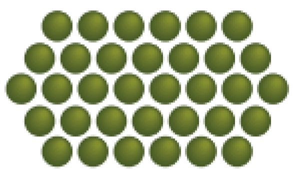
Sources: https://www.fujielectric.com/company/tech/pdf/58-04/FER-58-4-175-2012.pdf
http://www.digitalxplore.org/up_proc/pdf/387-153353684823-26.pdf

Improved Transformer Core – ABB

Internal structure of the material

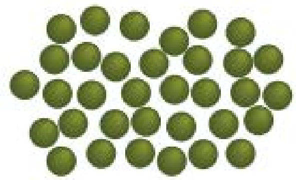


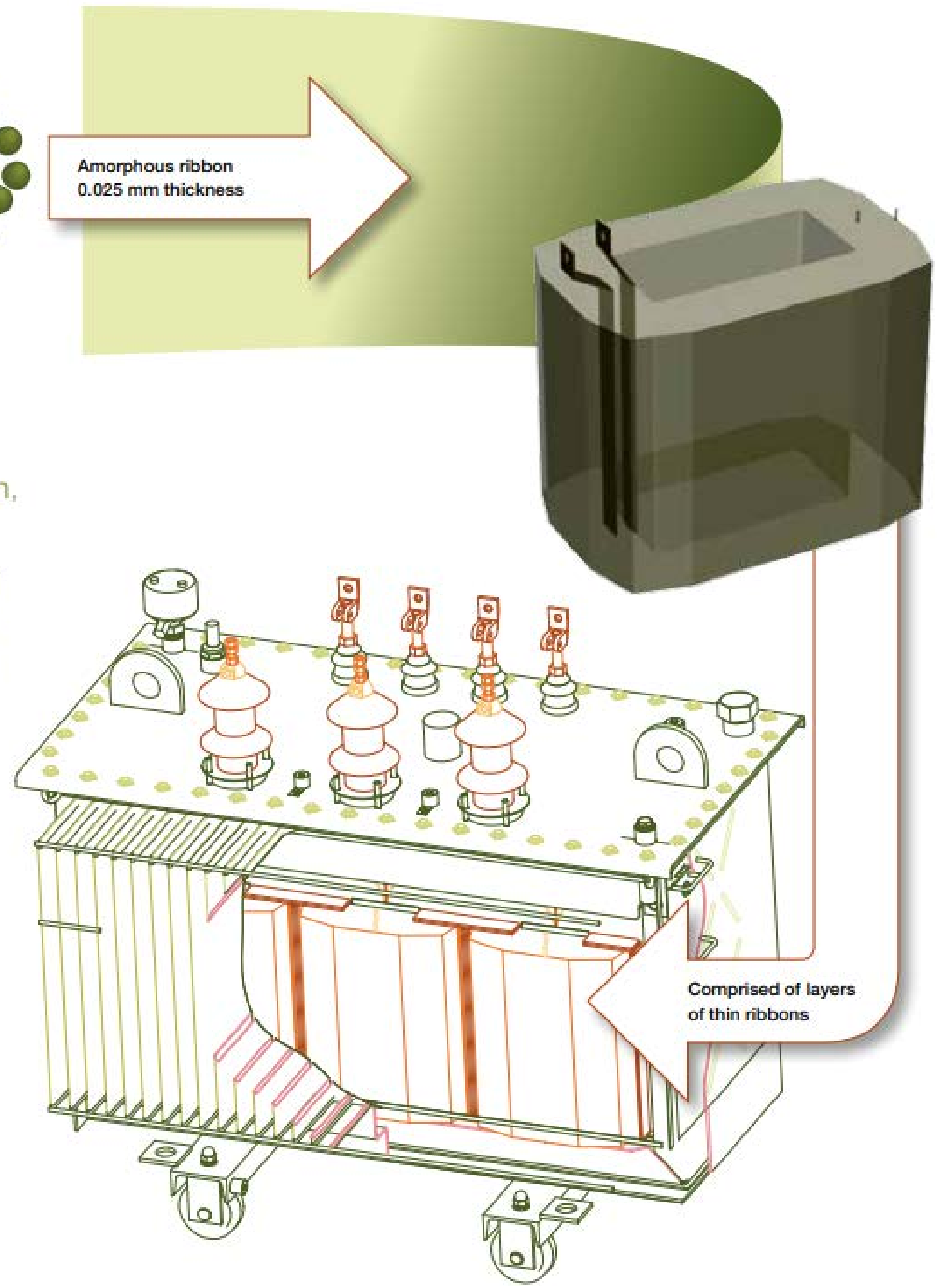
Amorphous steel
Disordered AMD



Conventional silicon steel
Ordered RGO

Amorphous steel





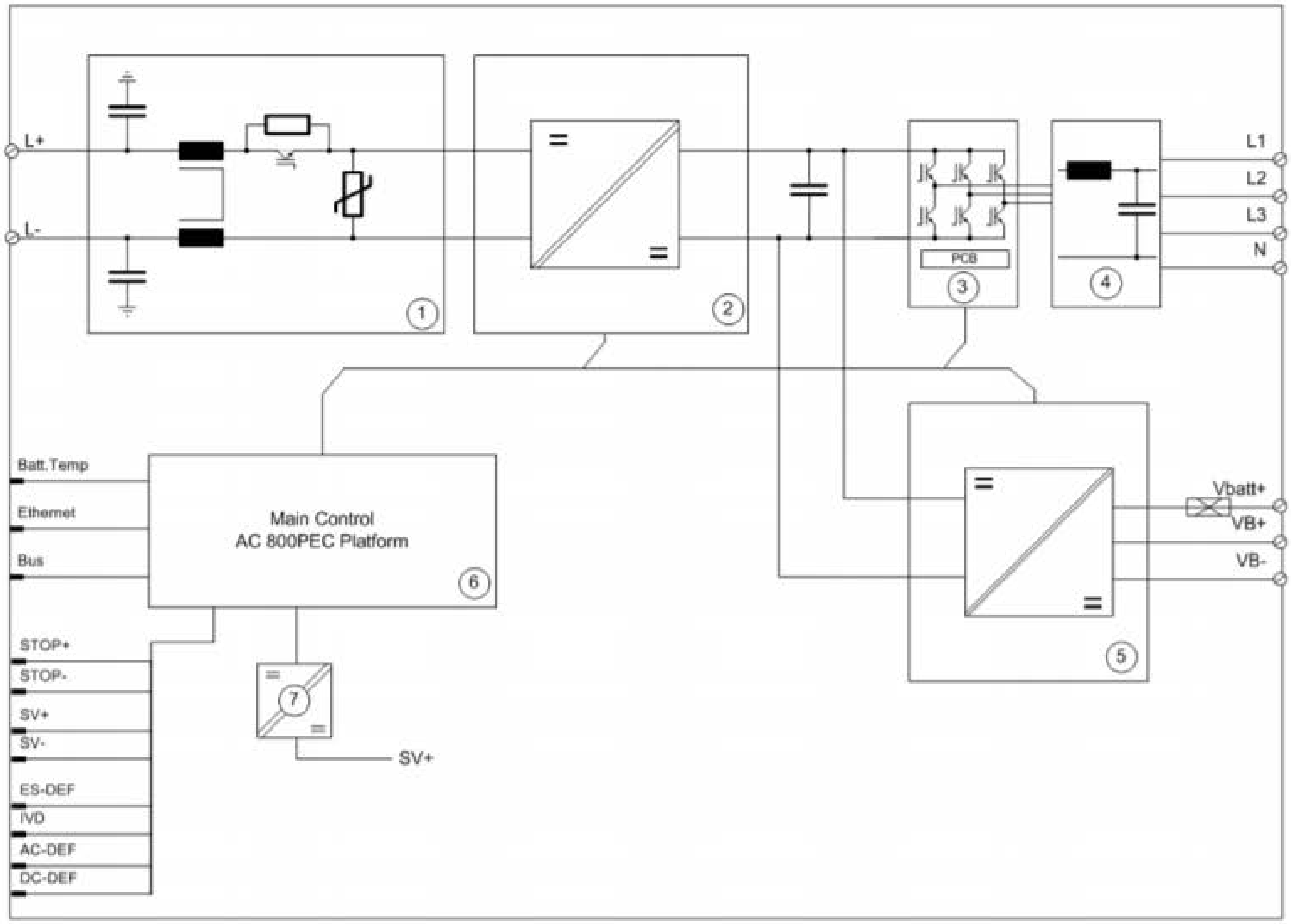
The absence of a crystalline structure enables easy magnetization, and combined with low thickness and high electrical resistivity helps to greatly **reduce no-load core losses**.

Comparison with maximum values from Commission Regulation (EU) N° 548/2014 with some example three-phase AM designs

Rating (kVA)	No-load losses (W) Regular Grain Oriented	No-load losses (W) Amorphous Metal	Loss reduction
100	145	65	55 %
250	300	110	63 %
400	430	170	60 %
800	650	300	54 %

Source: http://search.abb.com/library/Download.aspx?DocumentID=2425PL1257-W1-en&LanguageCode=en&DocumentPartId=&Action=Launch

Electric Locomotives – Auxiliary Power

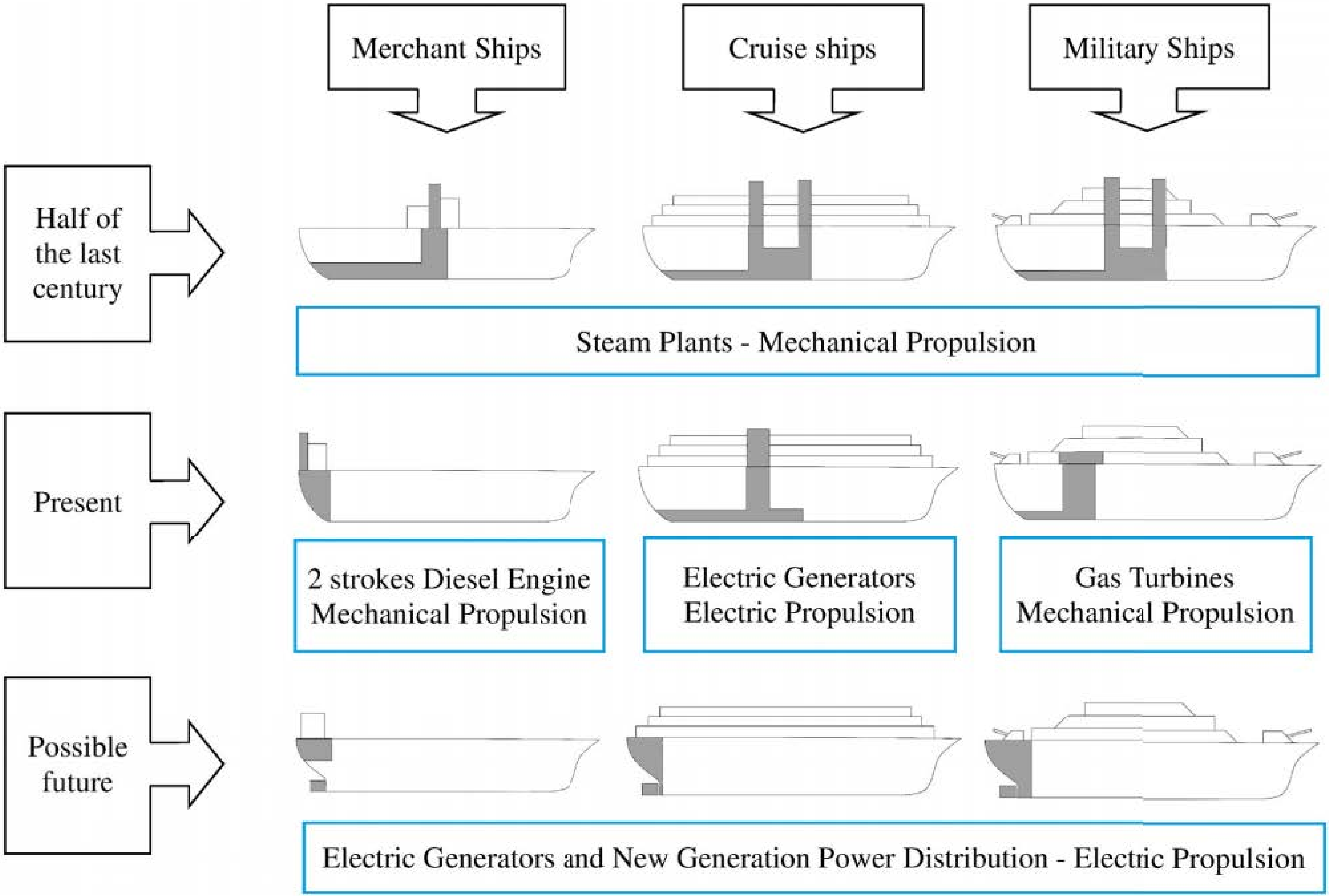


- The feeding voltage for a DC system can be 1,500 V, 750 V or 600 V

Source: https://library.e.abb.com/public/d9a842b9f69b4bbeb2aee69fe85c0d5e/BORDLINE%20M30_DC_750%20RevB%20EN.pdf

Electrification of Ships

Introduction to Ship Configurations



Sources: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7530867

Advantages of Electrical Propulsion

- Superior dynamics (start, arrest, speed variation) offered by electric motors over the conventional diesel motors (or gas turbines);
- Possibility of accommodating electrical motors with more flexibility, installing shorter shaft lines, or even outer rotating pods (thus eliminating the rudder and improving maneuverability);
- Reduced fuel consumption due to the modulation of thermal engines running (the number of generators on duty is adjusted in order to keep them working at their minimum specific fuel oil consumption);
- Higher comfort due to vibration reduction (thermal engines run at constant speed, therefore vibrations filtering is much efficient);
- High level of automation of the engine rooms and related reduced technical crew manning.

Sources: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7530867

Commercial Ship Specifications

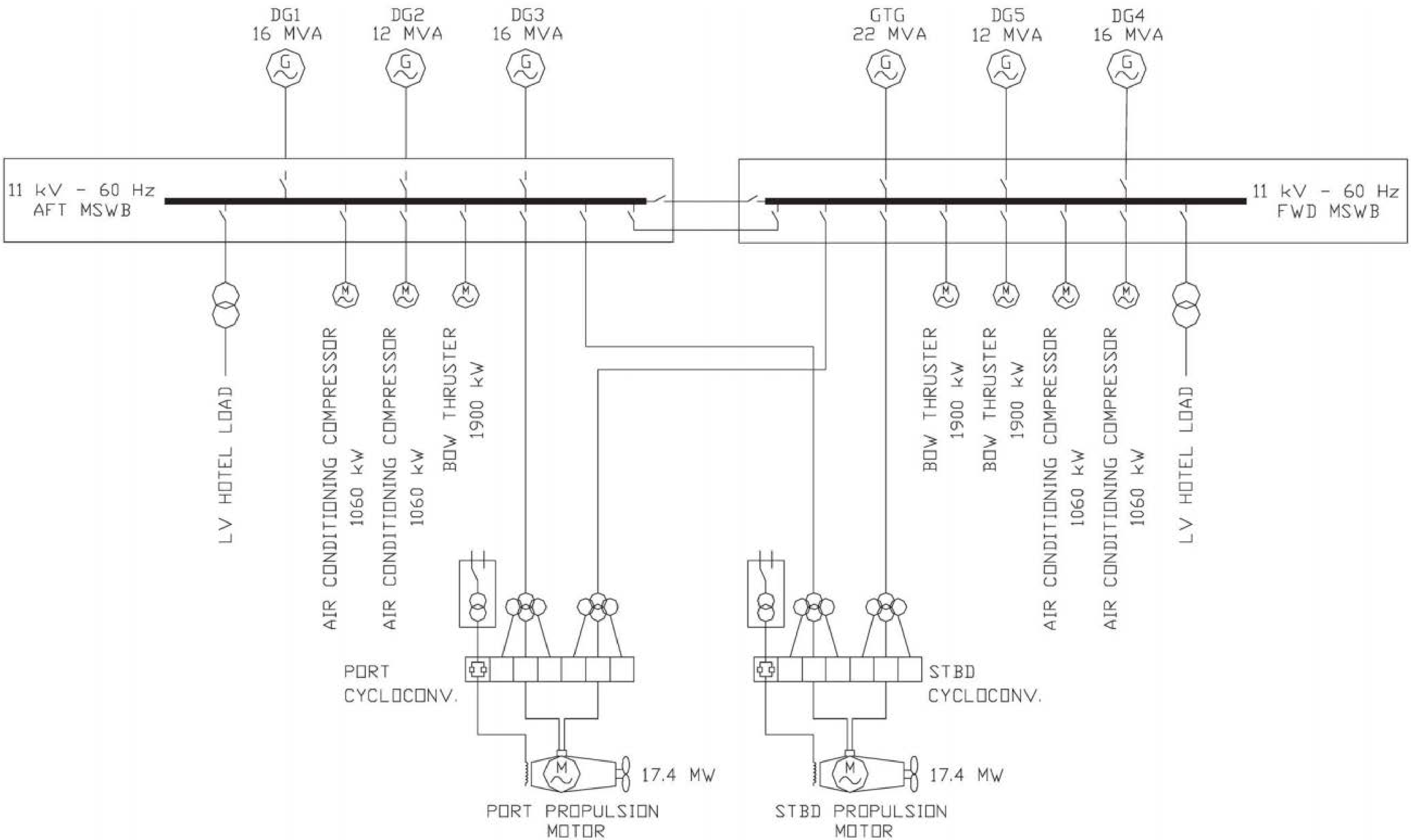
Typical cruise ship: Fincantieri Royal Princess.

ALL-ELECTRIC CRUISE SHIP (FINCANTIERI ROYAL PRINCESS), MOST SALIENT CHARACTERISTICS

Gross tonnage [GRT]	142.000
Life Saving Appliances	Up to 5600 people
Passenger Cabins	1780
Public areas [sqm]	40000
Length overall [m]	330
Breadth at Waterline [m]	38.4
Maximum Draft [m]	8.55
Contractual Service Speed [knots]	22
Propulsion system	4 LCI converters (48 pulse reaction) on two propellers
Continuous Propellers Output [MW]	2 x 18
Main Generators output [MW]	2 x 21 + 2 x 18
Main switchboards voltage [kV]	11
Total aggregated cable length [km]	4000
Total aggregated cableways length [km]	65
Secondary distribution switchboards	460
Installed circuit breakers	23000

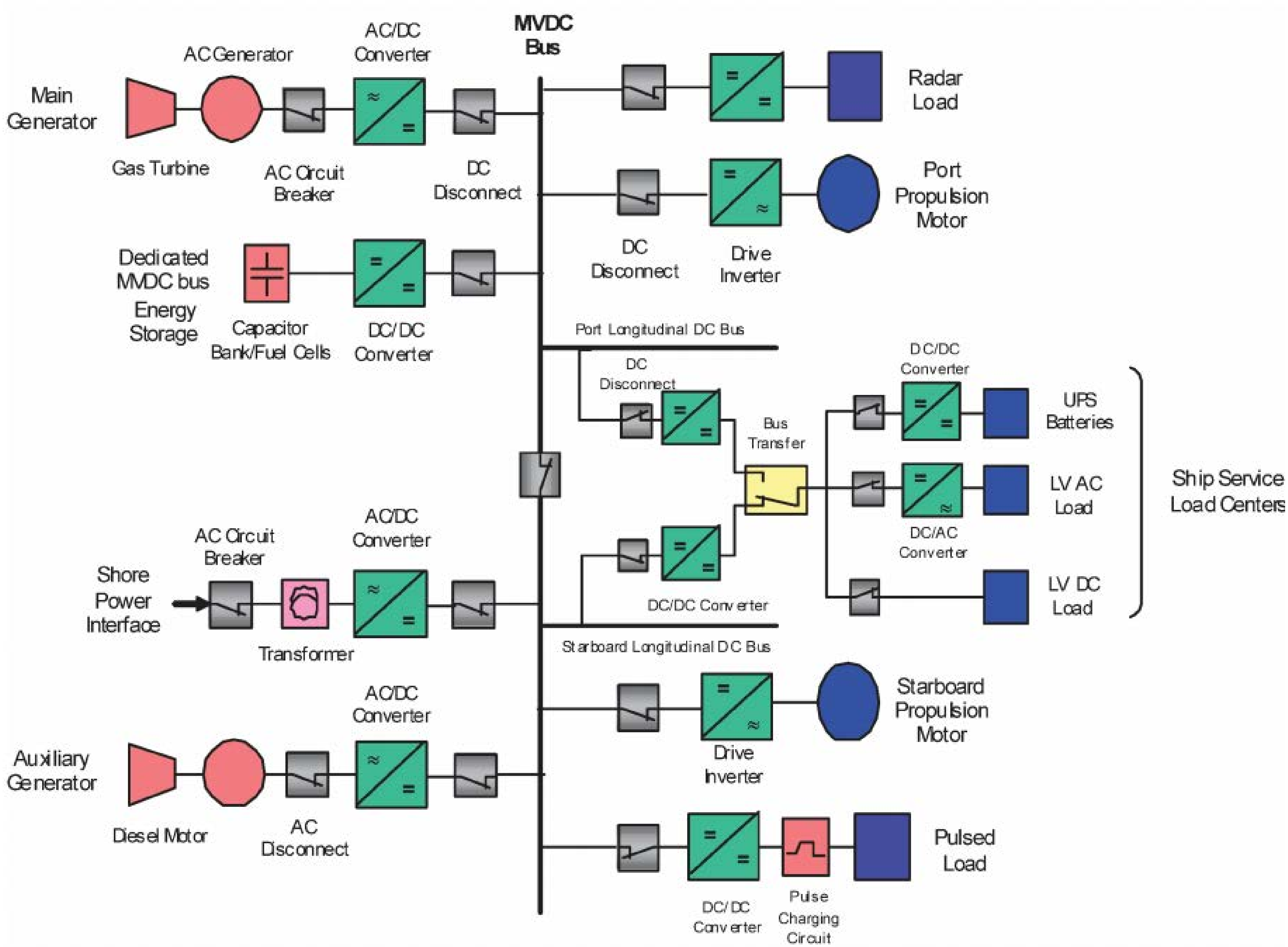
Sources: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7530867

Commercial Electric Ship Architecture



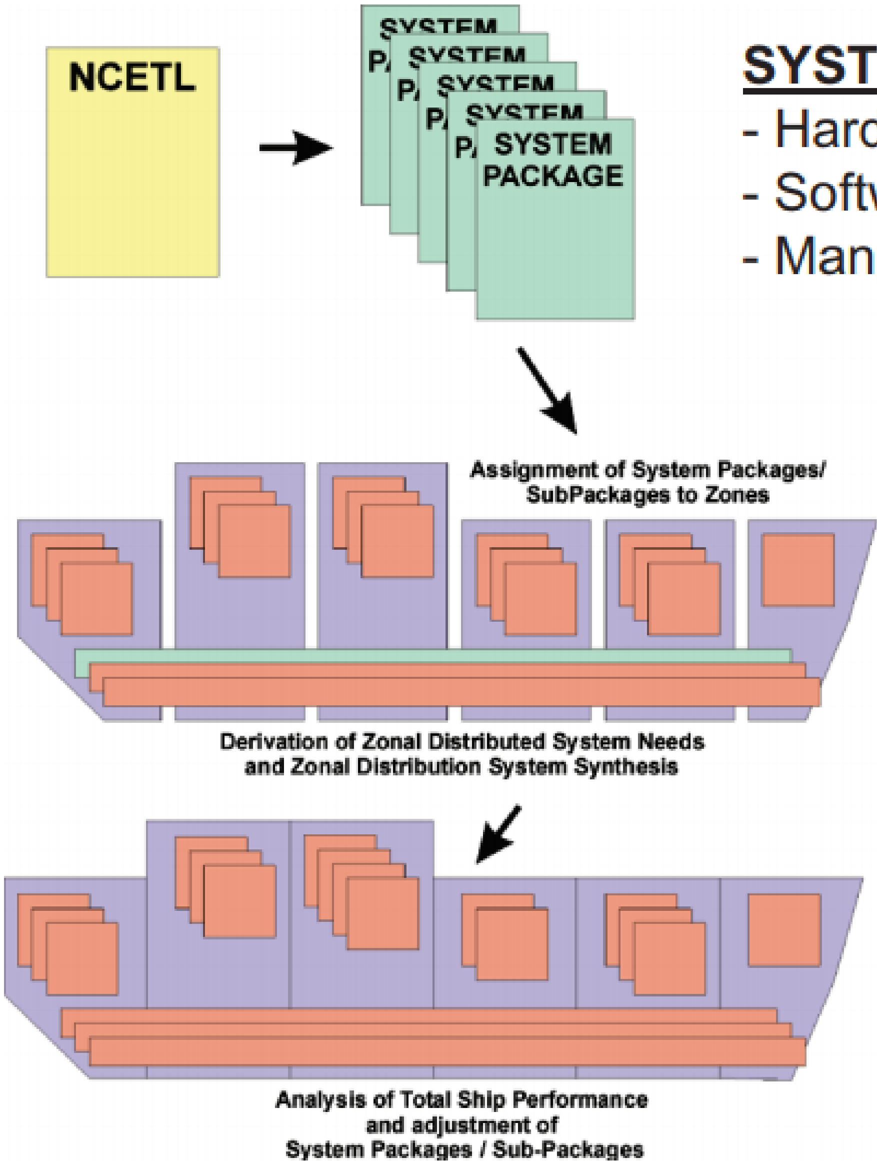
Sources: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7530867

Naval Electric Ship MVDC Architecture (Radial)



Sources: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7530867

Naval Electric Ship – Zonal Design



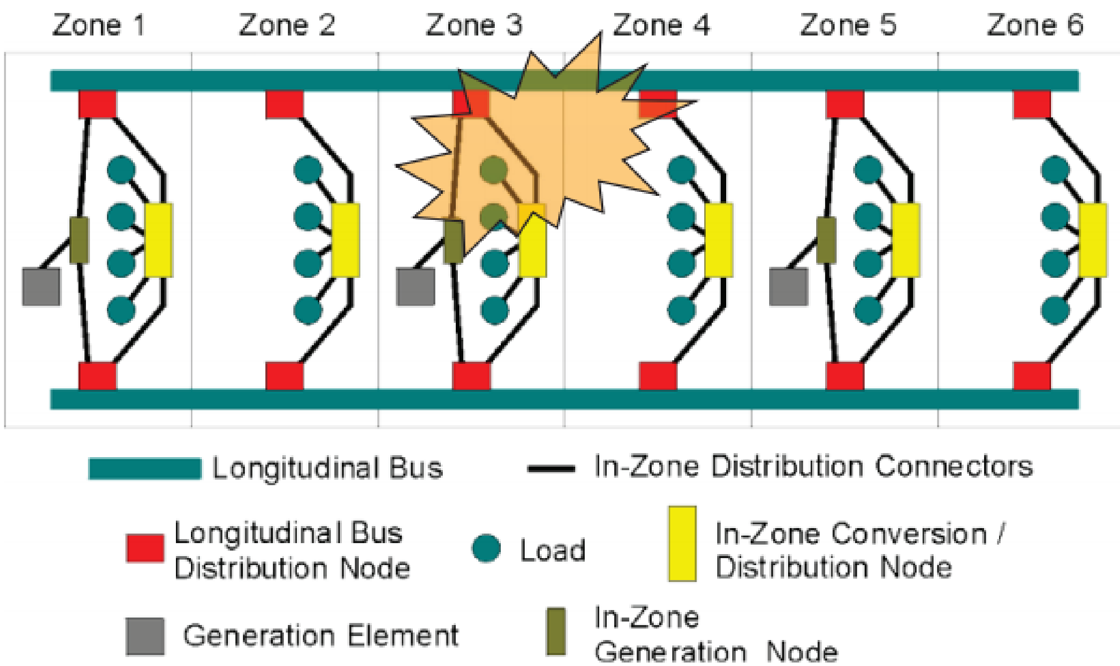
SYSTEM PACKAGE:
- Hardware
- Software
- Manpower

Zonal Design:
For capabilities that are required to survive, assign associated redundant Packages / Sub-packages such that loss of any 2 adjacent zones will leave sufficient functionality in undamaged zones.

Goal:
Make Survivability an "Open Loop" Design Process rather than a "Closed Loop" Process

Sources: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8069355

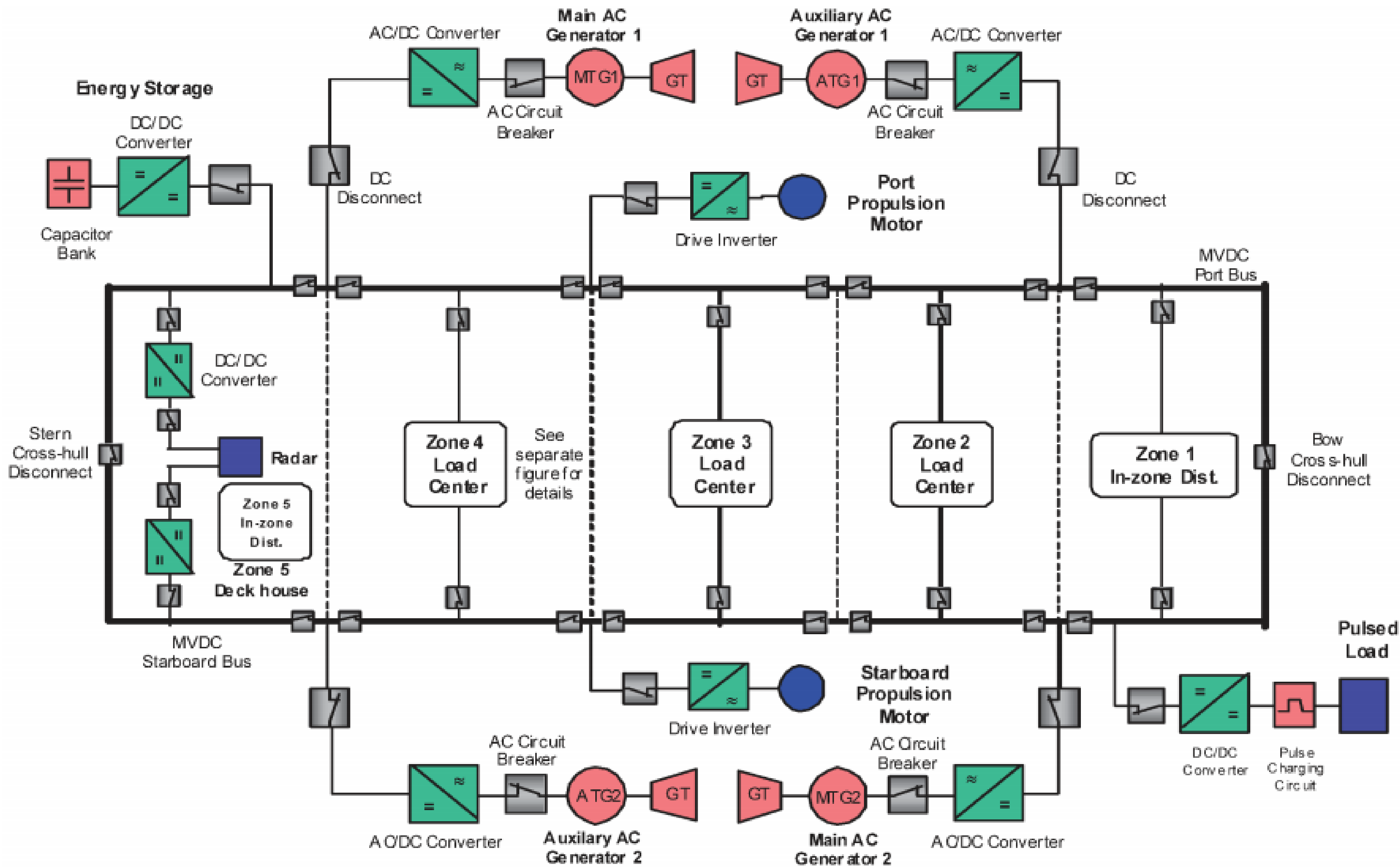
Naval Electric Ship – Survivability



- Provide capability to recover selected undamaged loads in a damaged zone.
  - Often requires redundant feeds.
- Which Loads to Select?
  - Non-redundant Mission Systems
  - Loads supporting damage control efforts

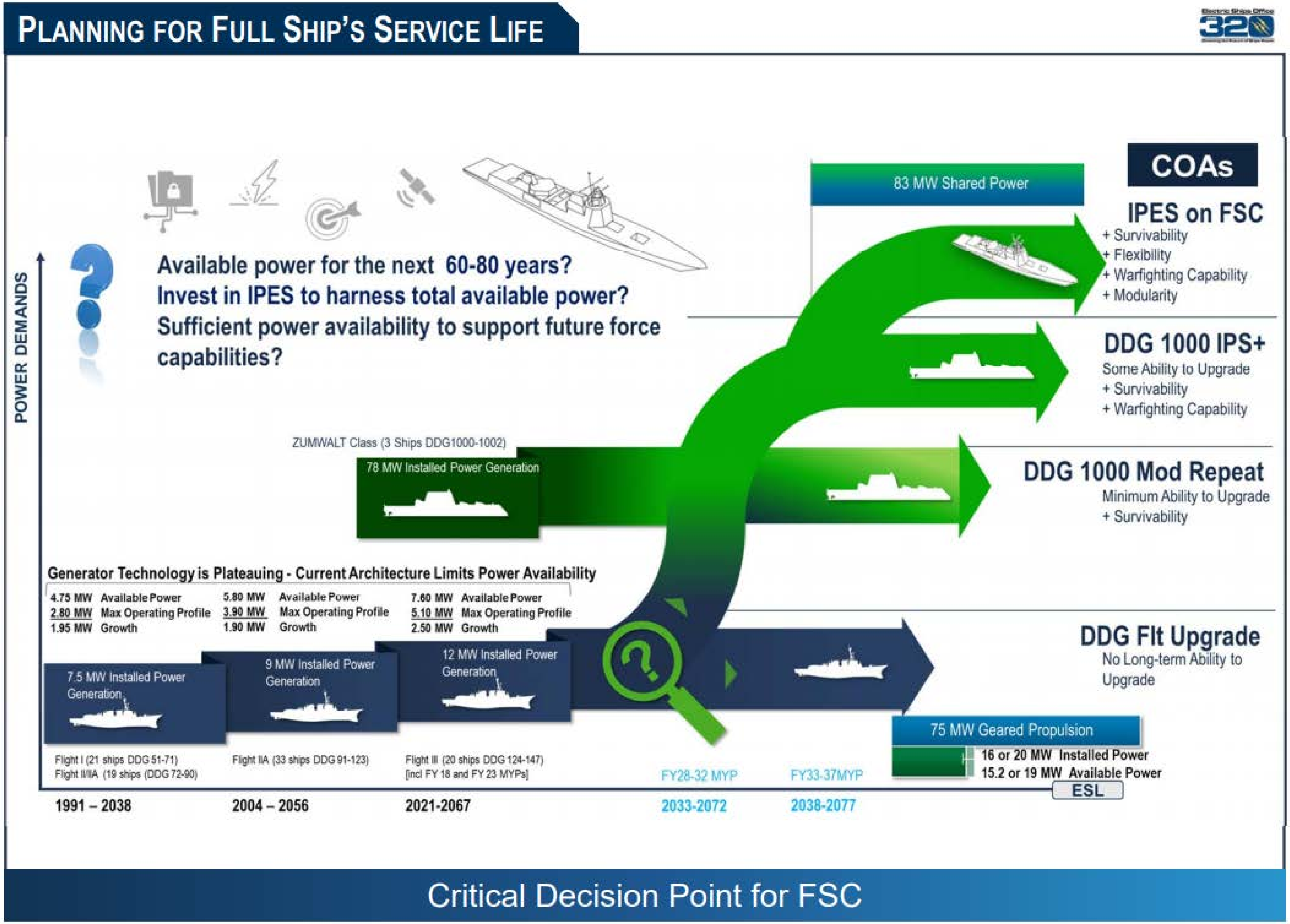
Sources: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8069355

Naval Electric Ship MVDC Architecture (Zonal)



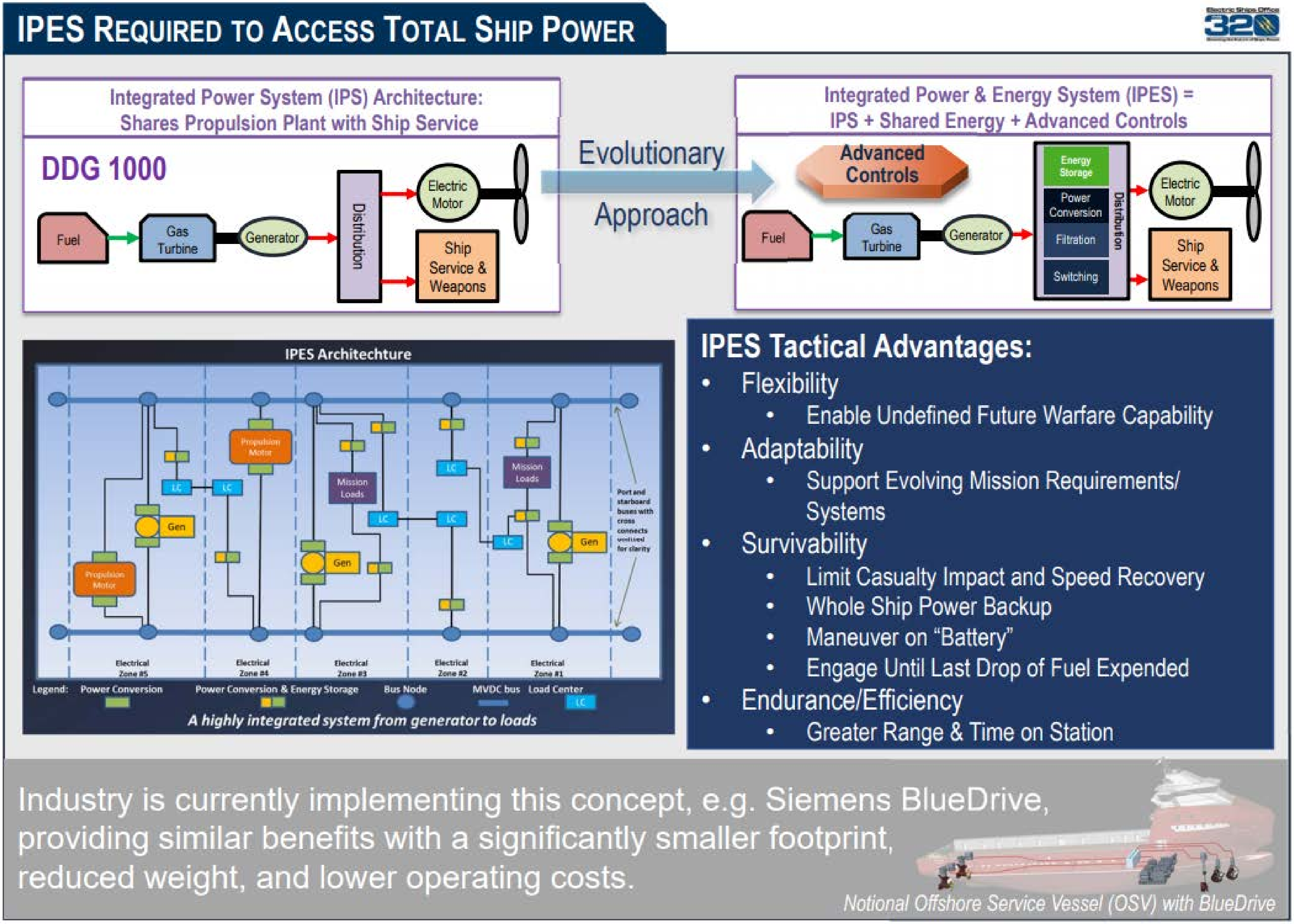
Sources: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7530867

Naval Electric Ship – Power Requirements



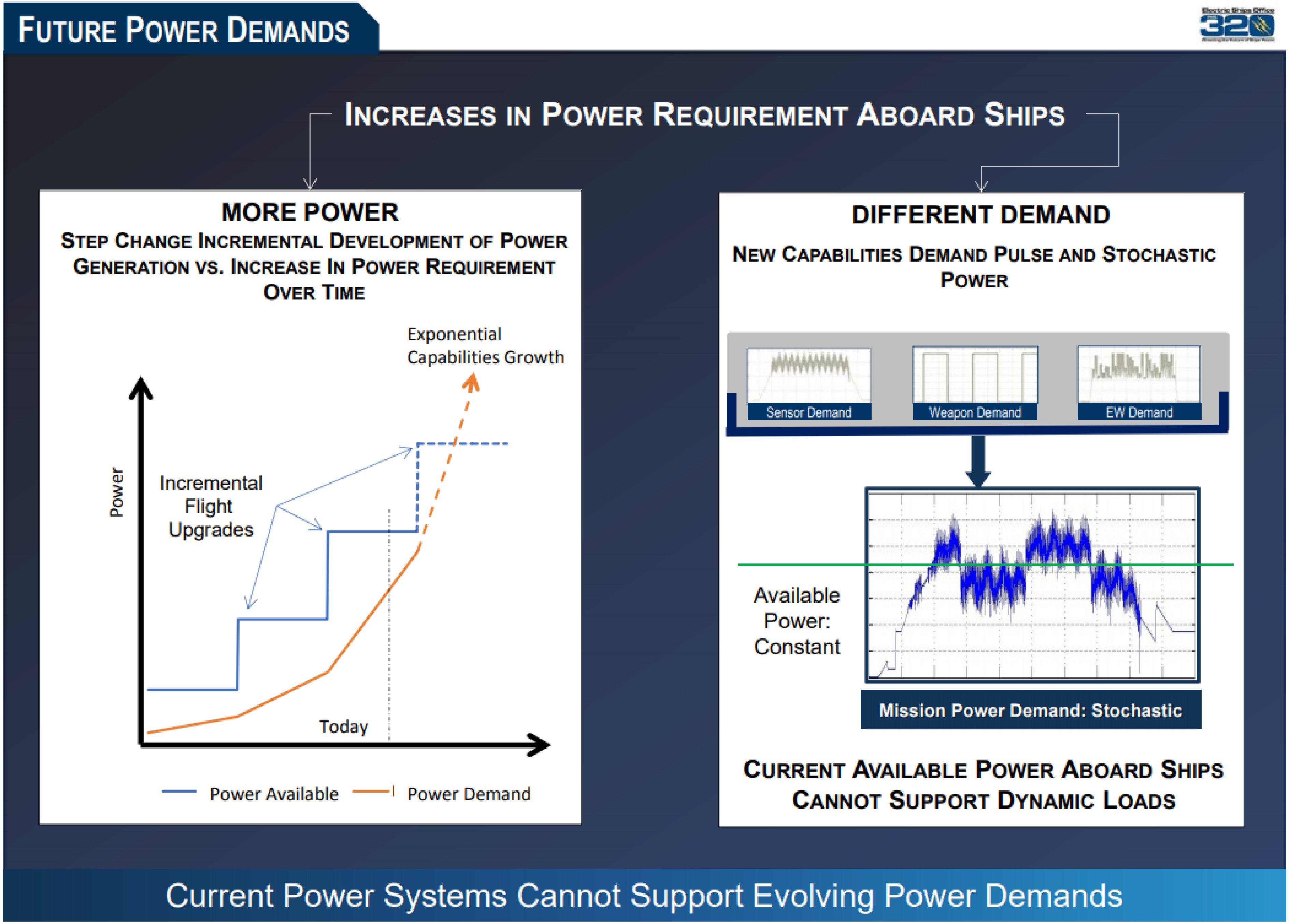
Sources: https://www.navsea.navy.mil/Portals/103/Documents/Exhibits/SAS2018/Markle-SurfaceNavyElectricalLeapForward.pdf?ver=2018-04-12-074110-193

Naval Electric Ship – Integrated Power Systems



Sources: https://www.navsea.navy.mil/Portals/103/Documents/Exhibits/SAS2018/Markle-SurfaceNavyElectricalLeapForward.pdf?ver=2018-04-12-074110-193

Naval Electric Ship Requirements

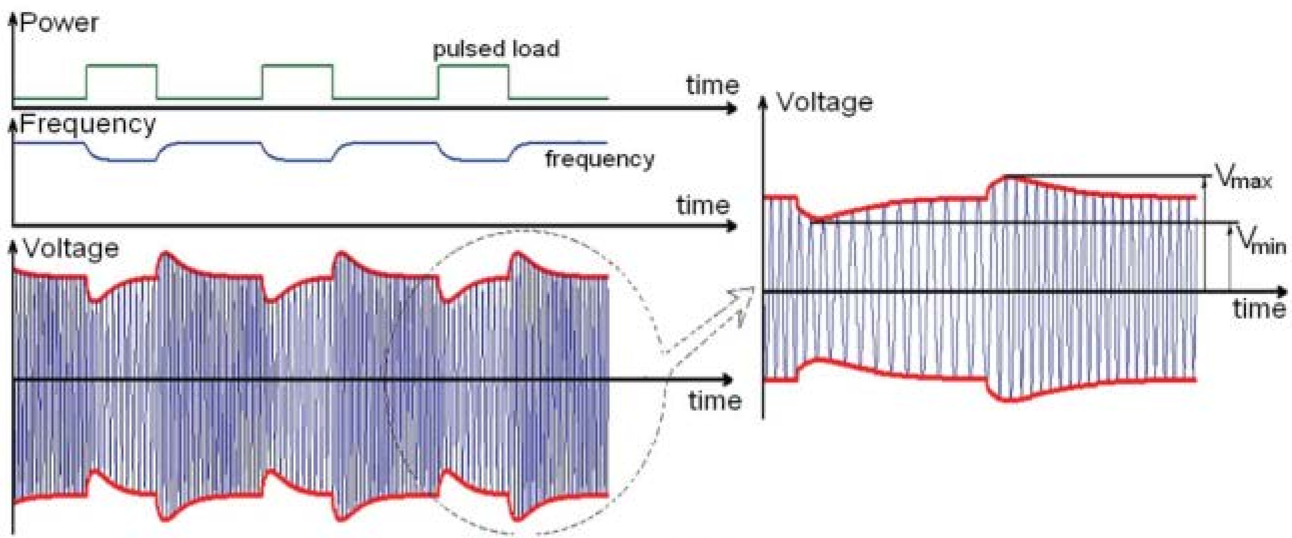


Sources: https://www.navsea.navy.mil/Portals/103/Documents/Exhibits/SAS2018/Markle-SurfaceNavyElectricalLeapForward.pdf?ver=2018-04-12-074110-193

Impact of Pulsed Load

HYPOTHETICAL SPECIFICATION OF INNOVATIVE HIGH-POWER WEAPON SYSTEMS

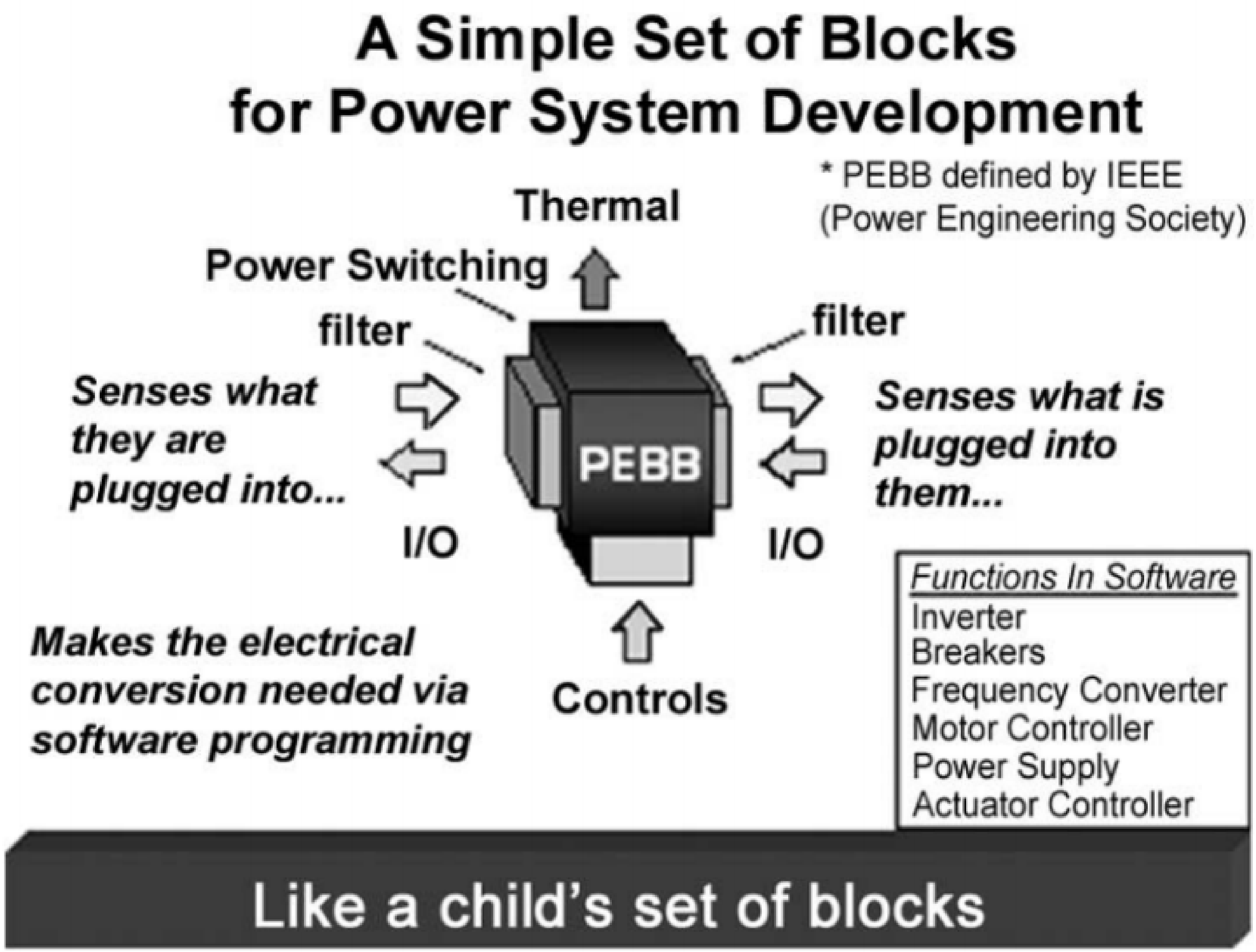
High Power System	Required Power [MW]	Weight [t]	Occupied Surface [m^2]
Radar Area Surveillance	4	70	137
Radar Ballistic Missile Defense Surveillance	17	250	272
Rail Gun	60	152	110
Laser (Medium Power) Point Defense	2	21	12
Laser (High Power) Missile Defence	60	65	297



Impact of a generic pulsed power load on an ac power system

Sources: https://www.navsea.navy.mil/Portals/103/Documents/Exhibits/SAS2018/Markle-SurfaceNavyElectricalLeapForward.pdf?ver=2018-04-12-074110-193

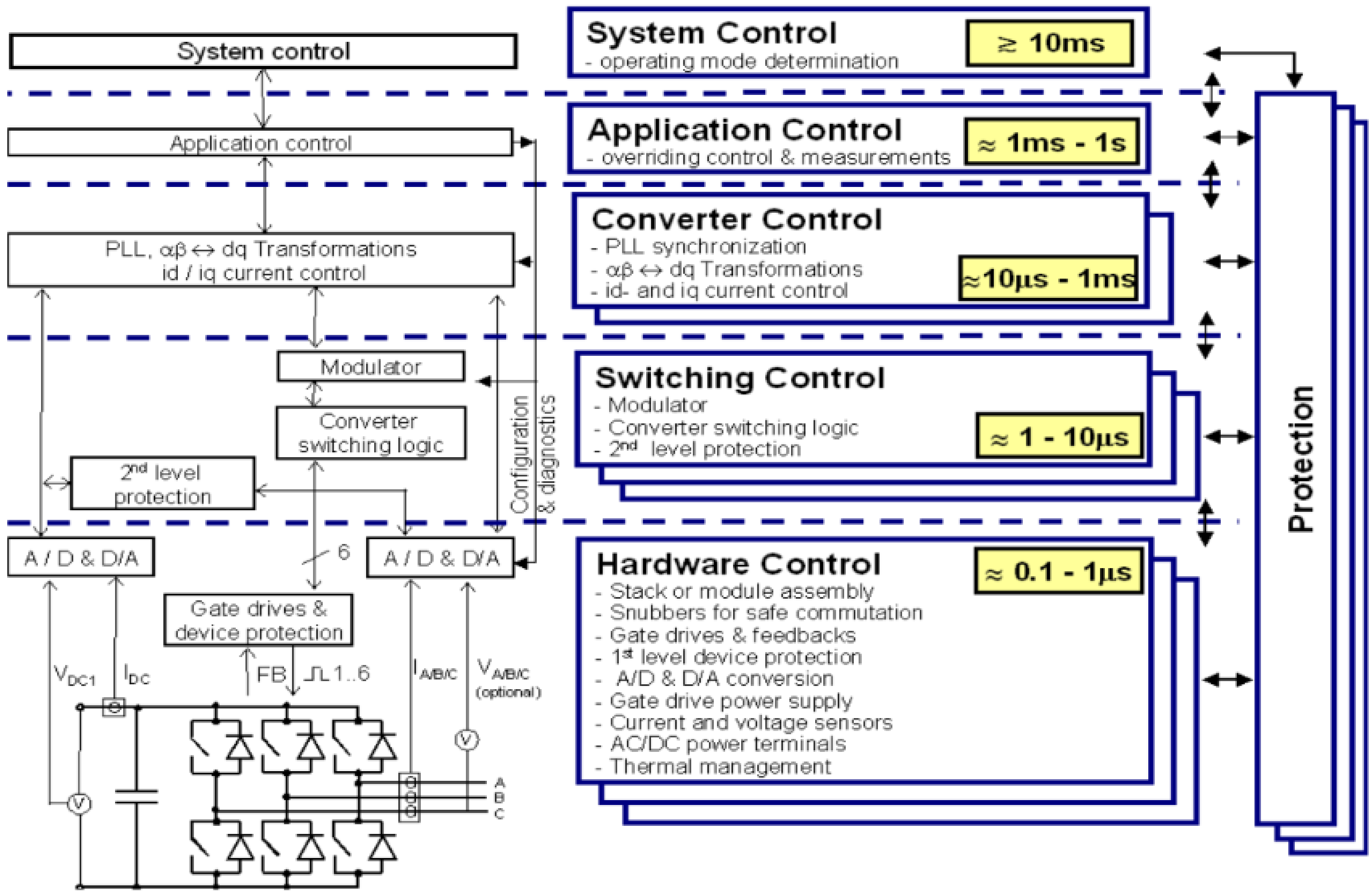
Power Electronics Building Blocks (PEBB)



Sources: https://www.navsea.navy.mil/Portals/103/Documents/Exhibits/SAS2018/Markle-SurfaceNavyElectricalLeapForward.pdf?ver=2018-04-12-074110-193

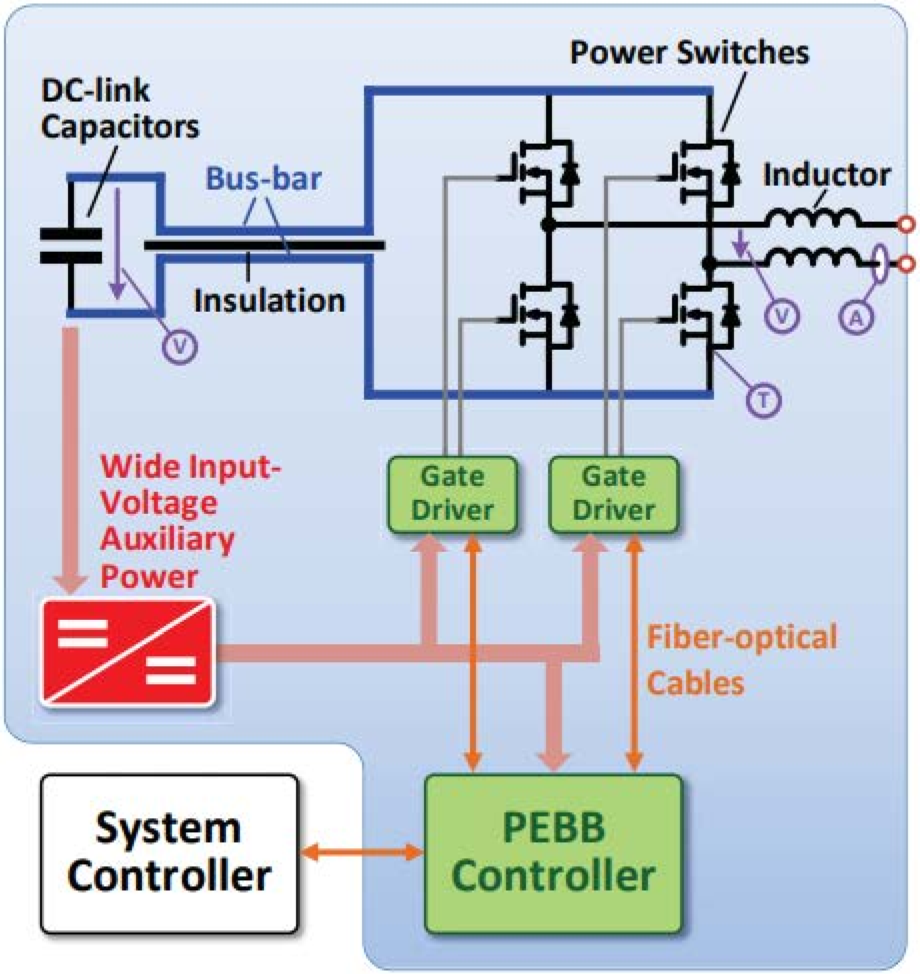
PEBB Control Layers

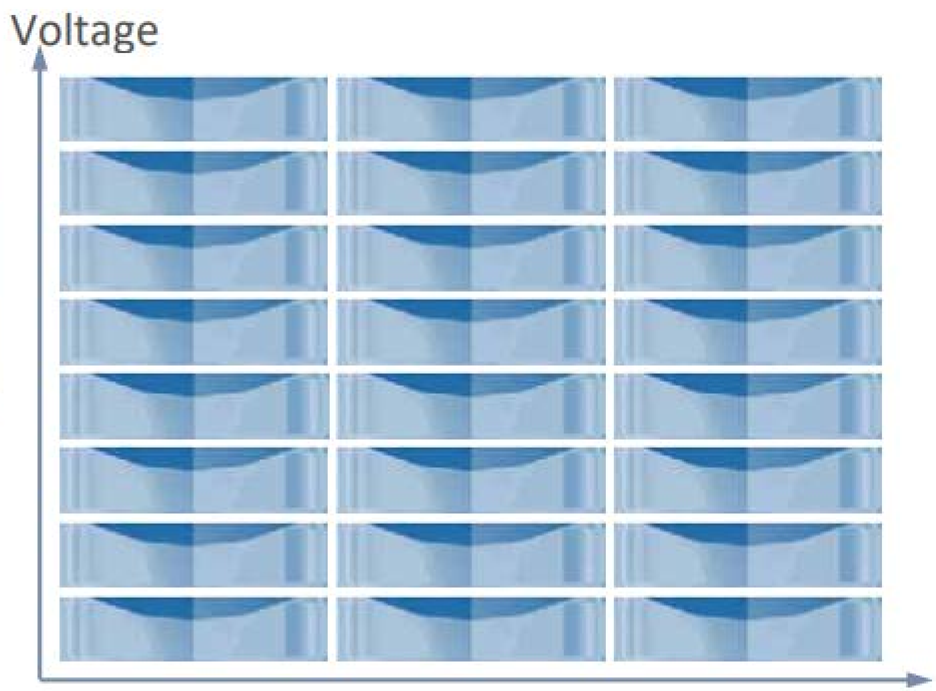
IEEE 1676-2010 - Guide for Control Architecture for High Power Electronics in Electric Power T&D Systems



Sources: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4123477

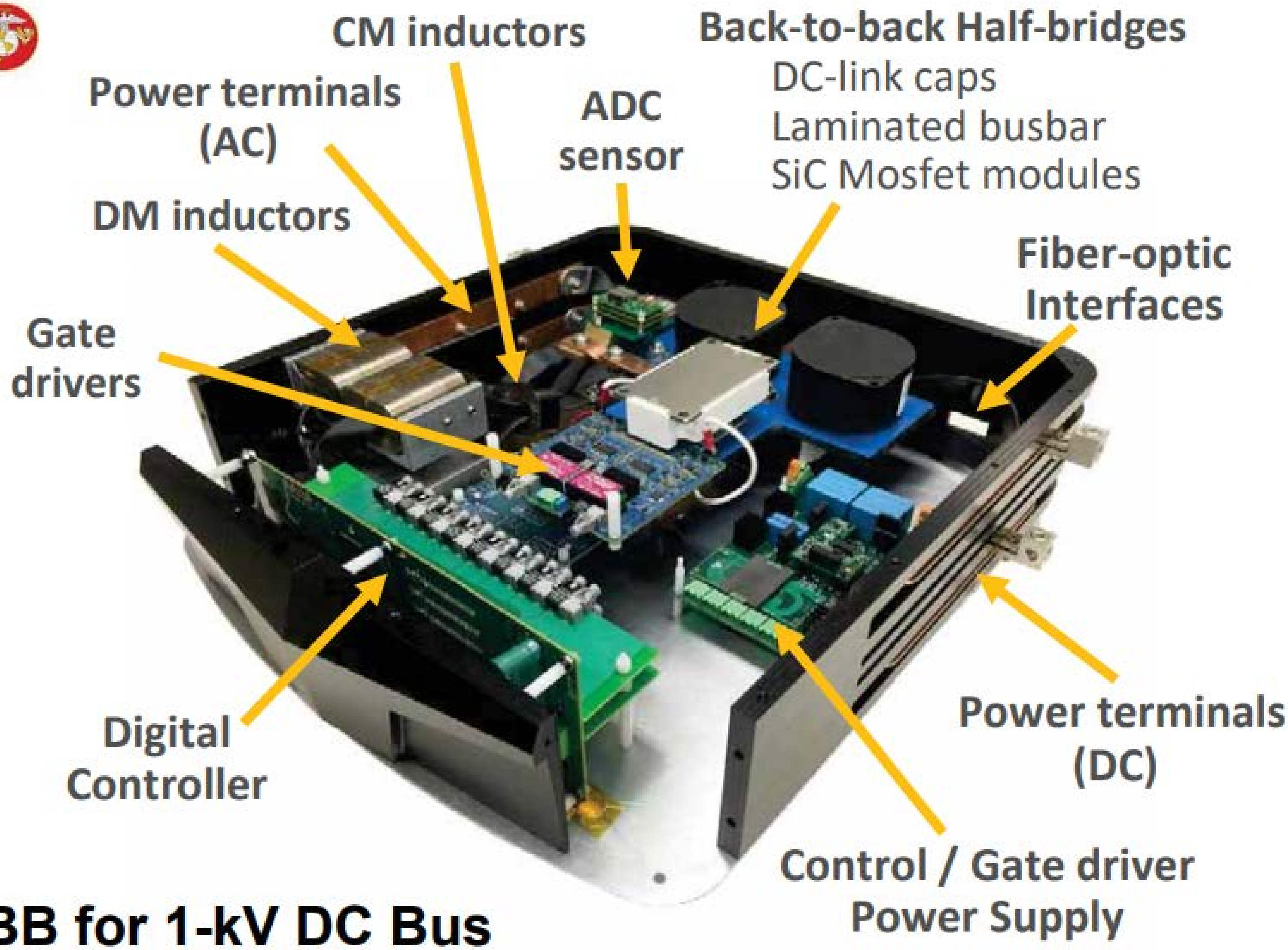
PEBB for MVDC (VTech - CPES)





Sources: https://www.energy.gov/sites/prod/files/2017/09/f36/%5B7%5D%20VT%20-%20Dushan%20Boroyevich.pdf

PEBB 1000

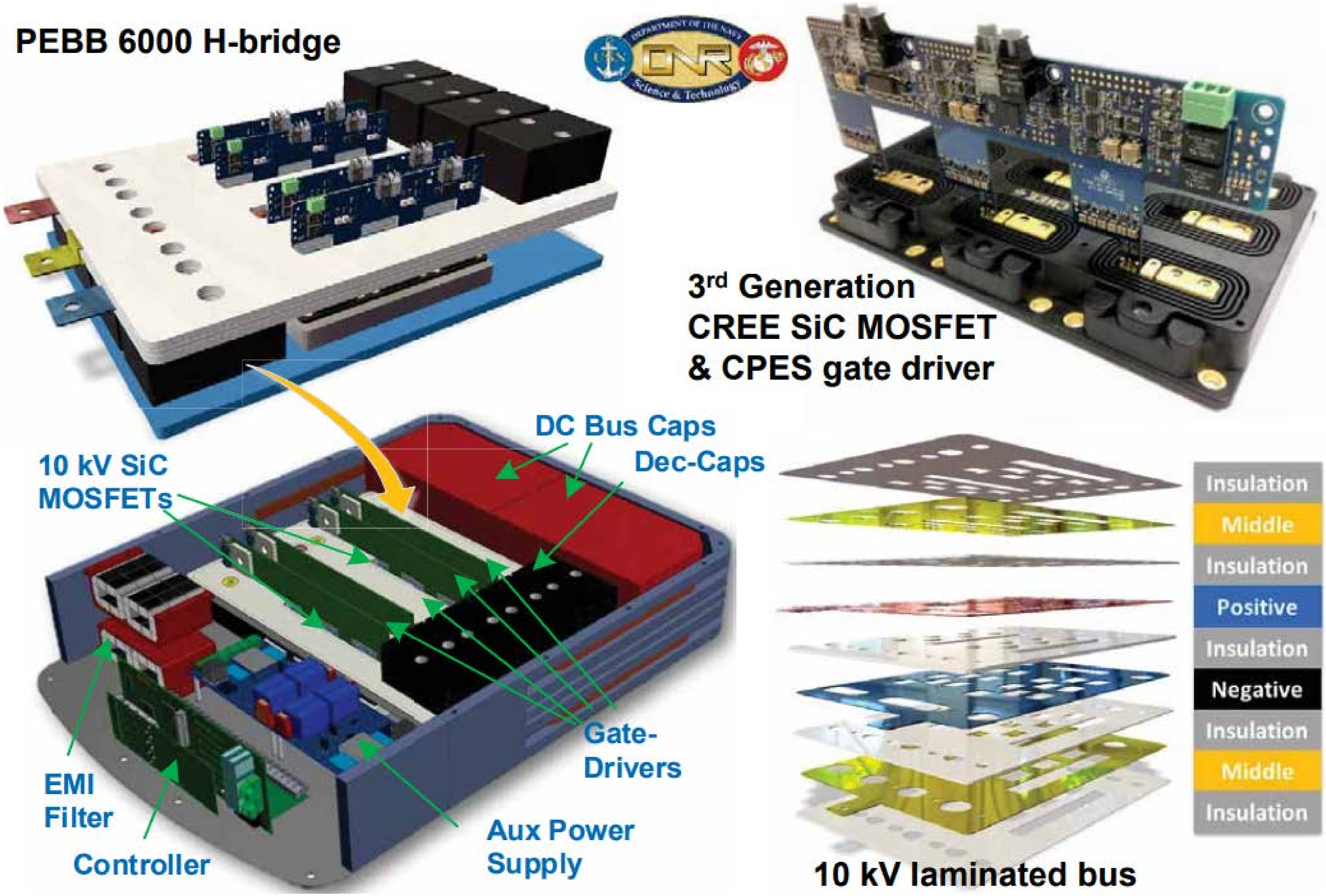


SiC PEBB for 1-kV DC Bus

100 kW, 100 kHz, 98%, 108 W/inch³

Sources: https://www.energy.gov/sites/prod/files/2017/09/f36/%5B7%5D%20VT%20-%20Dushan%20Boroyevich.pdf

PEBB 6000


PEBB 6000 H-bridge
3rd Generation
CREE SiC MOSFET
& CPES gate driver
DC Bus Caps
Dec-Caps
10 kV SiC
MOSFETs
Gate-
Drivers
EMI
Filter
Controller
Aux Power
Supply
Insulation
Middle
Insulation
Positive
Insulation
Negative
Insulation
Middle
Insulation
10 kV laminated bus

Summary

- Increased electrification in railways and ships – high power in several cases, well over 10 MW
- Scope of higher efficiency, smaller size and reduced environmental burden
- 'Electronic Transformers' becoming popular
- Health analytics for power systems – growing trend of data-driven approaches and automation
- Machine learning based digital twin and design optimization becoming popular

Electrification: For improved mass transportation!!

UH Power Courses and Degrees

- Two certificate programs
- MSEE degree program with specialization in Power & Energy Systems
- Distant PhD program – reduced course requirement for experienced engineers
- All the below courses can be taken online!

Power Electronics and Renewable Energy:

ECE 6305 Power Electronics Converters and Control

ECE 6343 Renewable Energy and Distributed Power Generation

ECE 6317 Adjustable speed Motor Drive systems

ECE 6318 Power Converters: Modeling and Applications

Power Systems and Smart Grid:

ECE 6326 Power System Analysis

ECE 6327 Smart Grid Systems

ECE 6329 Power System Protection, Monitoring and Control

ECE 6334 High Voltage Electrical Substations Design and Architecture

ECE 6343 Renewable Energy and Distributed Power Generation

Please visit – http://pemses.ece.uh.edu/courses-offered/

Thank You!

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