

A stylized graphic of a ship's hull and superstructure in dark blue and teal, with a white lightning bolt striking the side. The background features a dark blue gradient with a pattern of lighter blue diagonal stripes.

[FLEXSHIP] Short Course - Electrification and Digital Twins for Green Shipping

Session 3

DATE

6/10/2025

FLEXSHIP

Season 3

Control architecture



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1. Control philosophy

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2. Control architecture

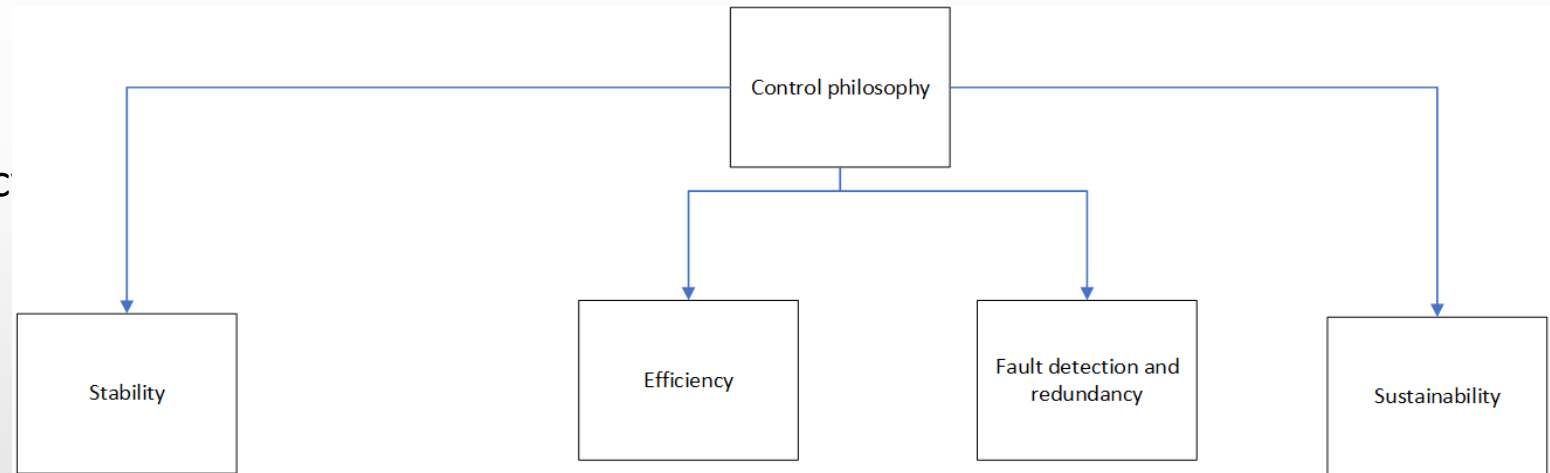
- Control functions

3. Conclusion

Control philosophy refers to the set of goals that a control system follows.

What are the **primary** role of control systems in ship power system?

- Stability
- Efficiency
- Fault tolerant strategy and redundancy
- Sustainability



What is stability? There are various definition of stability in energy system application. In power system, **asymptotic** stability

Why Stability Is Important?

- **Avoids blackouts:** Instability can cause full or partial power loss—very dangerous in navigation, propulsion, or safety systems.
- **Protects sensitive equipment:** Voltage and frequency deviations can **damage electronics, motors, and navigation systems.**
- **Ensures safety:** Power system failure can jeopardize propulsion, steering, fire control, and crew safety.
- **Improves reliability and availability** of energy onboard, especially for naval, passenger, or offshore support vessels.

Efficiency is the ratio of useful output energy (mechanical propulsion power + electrical power for onboard systems) to the total input energy (from fuel or electricity). It indicates how effectively the ship's power system uses the available energy.

Why Efficiency Matters

- **Fuel Savings:** Higher efficiency means less fuel consumed, reducing operating costs and emissions.
- **Environmental Impact:** Improves carbon footprint and reduces pollutants like NO_x, SO_x, and particulate matter.
- **Performance:** Efficient power systems provide better responsiveness and range.
- **Regulatory Compliance:** Meeting efficiency standards (like IMO's Energy Efficiency Design Index, EEDI) is mandatory for new ships.

1.3 Efficiency

Key Types of Efficiency in Ship Power Systems

1. Thermal Efficiency

1. Applies mainly to engines (diesel, gas turbines).
2. Measures how well the engine converts the chemical energy in fuel into mechanical energy.
3. Higher thermal efficiency means less fuel consumed for the same power output.

2. Propulsion Efficiency

1. Measures how effectively mechanical power from the engine or motor is converted into thrust to move the vessel through water.
2. Depends on propeller design, hull form, and operational conditions.
3. Can be improved by optimizing propeller size, pitch, and minimizing hull resistance.

3. Electrical Efficiency

1. Relevant for electric motors, generators, and battery systems in electric or hybrid vessels.
2. Reflects losses in electrical conversion and transmission.
3. High-efficiency motors and power electronics reduce energy losses.

4. Overall System Efficiency

1. Combines thermal, electrical, and propulsion efficiencies to represent the ship's total energy conversion performance.
2. Includes losses in auxiliary systems (cooling, pumps, lighting).

1.4 Fault strategy

Fault detection and redundancy

Fault detection refers to the methods and techniques used to identify when a system component or process is not functioning correctly or has failed.

Why Fault Detection Matters

- Early detection of faults prevents minor issues from escalating into major failures or accidents.
- It enables timely maintenance or corrective action, improving safety and reliability.
- Minimizes downtime and operational disruptions.

Fault Types Detected

- Electrical faults (short circuits, open circuits)
- Mechanical faults (bearing wear, cracks)
- Thermal faults (overheating)
- Software/hardware faults (communication errors, sensor failures)

Fault detection and redundancy

Common Fault Detection Methods

- **Sensors and monitoring:** Continuous measurement of voltage, current, temperature, vibration, pressure, or other key parameters.
- **Model-based detection:** Comparing actual system behavior to a mathematical model or expected patterns to spot deviations.
- **Signal processing and filtering:** Analyzing sensor data for anomalies or signatures of faults.
- **Machine learning:** Using data-driven models to detect unusual patterns or predict faults.
- **Threshold alarms:** Setting limits on parameters to trigger warnings when exceeded.

1.4 Fault strategy

Fault detection and redundancy

Redundancy

Redundancy means including extra components, systems, or pathways beyond what is strictly necessary, so if one part fails, the system can continue functioning.

Why Redundancy Is Important

- Increases system **reliability** and **availability**.
- Provides **fail-safe** capabilities, critical in safety-sensitive systems (e.g., aviation, marine propulsion, power grids).
- Allows maintenance or repairs without shutting down the entire system.

Types of Redundancy

- **Hardware Redundancy:** Duplicate or triplicate physical components (e.g., multiple batteries, parallel processors, backup generators).
- **Software Redundancy:** Multiple algorithms or programs perform the same function to cross-check results.
- **Information Redundancy:** Use of checksums, error-correcting codes to detect and correct data errors.
- **Functional Redundancy:** Different systems or methods that achieve the same outcome, offering alternative operational paths.

Sustainability in ship power systems refers to designing, operating, and maintaining the ship's energy generation and propulsion systems in a way that minimizes environmental impact, conserves resources, and supports long-term ecological and economic viability.

There are two aspects in sustainability

Environmental Sustainability

Economic Sustainability

Environmental Sustainability

- Reducing emissions:** Transitioning from fossil fuels (like heavy fuel oil or diesel) to cleaner energy sources such as batteries, LNG, hydrogen, or hybrid systems reduces greenhouse gas (GHG) emissions, sulfur oxides (SOx), nitrogen oxides (NOx), and particulate matter.
- Energy efficiency:** Optimizing power generation, propulsion, and onboard energy use to minimize fuel consumption and waste. Technologies include efficient engines, propeller design, waste heat recovery, and advanced energy management systems.
- Minimizing pollution:** Avoiding oil spills, reducing underwater noise pollution, and managing waste and ballast water to protect marine ecosystems.

Economic Sustainability

- Cost-effectiveness:** Sustainable power systems aim to reduce operational costs over the vessel's lifecycle, balancing initial investments with fuel savings and lower maintenance costs.
- Regulatory compliance:** Meeting increasingly strict international regulations (e.g., IMO's MARPOL Annex VI for emissions, EEDI standards) helps avoid fines and operational restrictions.
- Future-proofing:** Incorporating adaptable or modular power systems that can evolve with advancing technologies and regulations.



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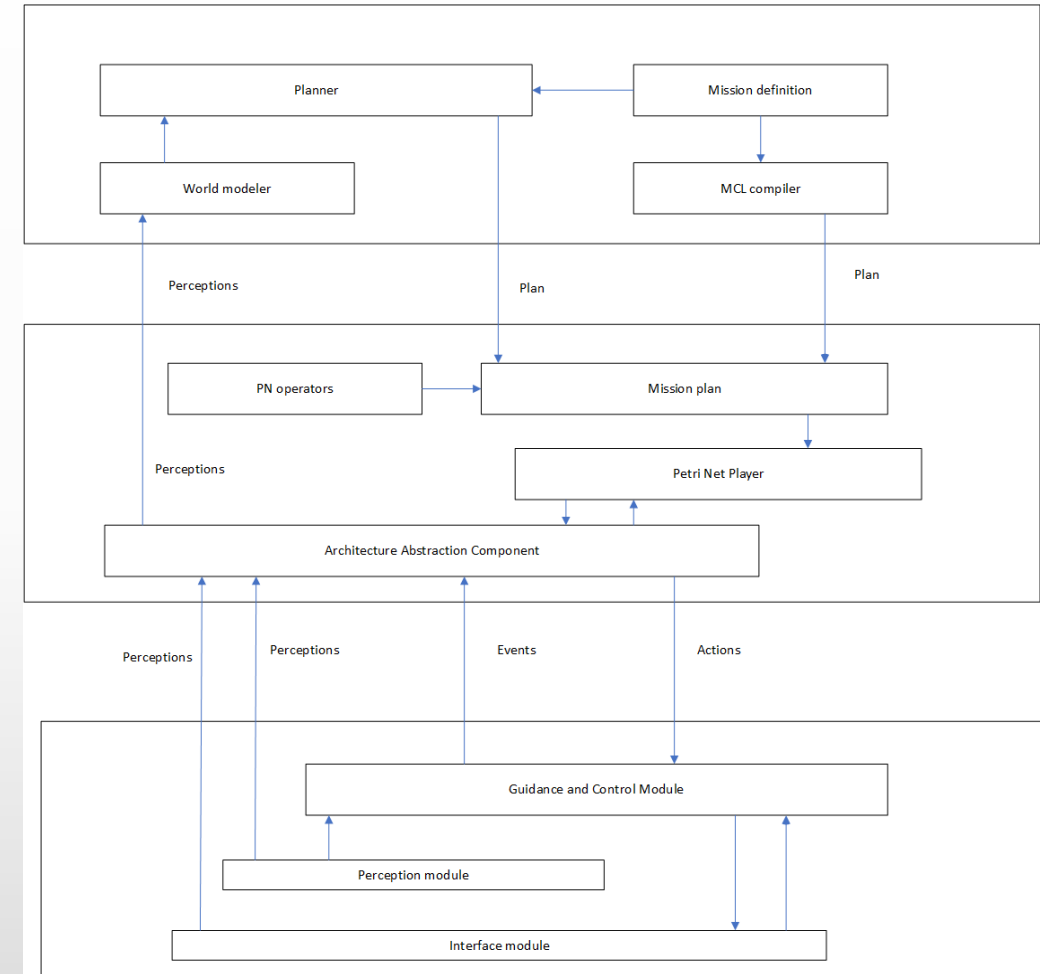
Mission layer

What is mission plan? How to reach from point A to point B in an optimal way?

The architecture consists of several subcomponents:

- World model
- Planning
- Mission definition
- Compiler

The mission layer communicates with the lower layers



Ref: [10.1109/JOE.2012.2205638](https://doi.org/10.1109/JOE.2012.2205638)

2.1 Control functions

Energy management

Energy management is responsible for load distribution

- Load distribution between all distributed energy resources, including batteries and gensets
- Emissions control (NO_x, SO_x)
- Greenhouse gas emission control

2.1 Control functions

Battery Management System (BMS)

Manages energy storage systems like lithium-ion batteries.

- State of charge (SoC) and health (SoH) monitoring
- Charging/discharging control
- Thermal management and safety shutdowns
- Balancing across battery cells or packs

2.1 Control functions

Fire and Safety Control Systems

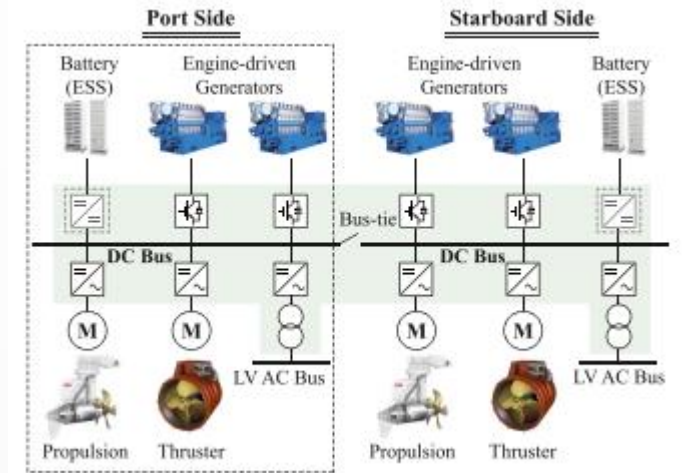
Monitors fire detection, suppression, and emergency shutdowns.

- Fire alarms and sprinkler activation
- Emergency shutoff of fuel and ventilation systems
- Lifeboat and life raft control systems

Power management system structure

The role of PMS is summarized as below:

- Managing low level controllers
- Communicate with BMS and the energy management system
- Regulate the power and load distribution for the purpose of propulsion.



Ref: [10.1109/TEC.2024.3434454](https://doi.org/10.1109/TEC.2024.3434454)

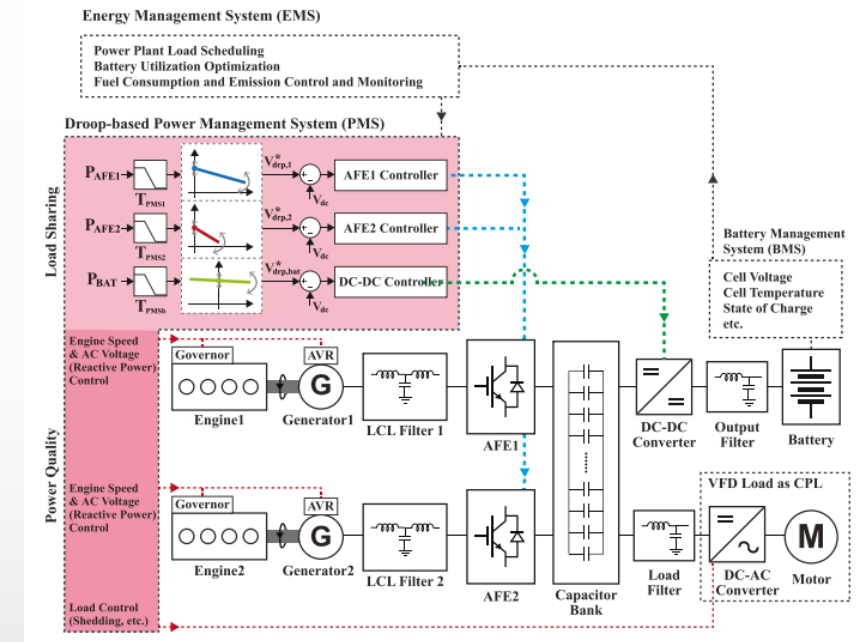
For DC topologies, one main challenge is **stability** of the power system. Stability highly depends on the operating points and the local control systems.

Primary control system

One of the main duties of the PMS is real time load distribution and stabilize the power system, due to the change in the load demand.

The primary strategy is the **droop control** methodology.

The aim is to control the **active** and **reactive** power and load distribution based on the changes in the frequency and voltage level.



Ref: [10.1109/TTE.2023.3296099](https://doi.org/10.1109/TTE.2023.3296099)

Stability

Stability in power systems refers to tracking the desired control setpoints

The primary strategy is the **droop control** methodology.

Droop control is a **decentralized** control method used primarily in power systems—especially in microgrids and inverter-based systems—to share load among multiple sources (like generators or inverters) **without communication**.

Droop principle:

Active power–frequency (P–f) droop

Reactive power–voltage (Q–V) droop

As conclusion, we would like to summarize the main role of control architecture in below

- The major role of control architecture is to execute a particular mission plan with respect to control philosophy
- The control philosophy contains stability, redundancy, fault detection techniques, and sustainability
- All control functions, including BMS, PMS, and EMS communicate to reach the control philosophy.
- In autonomous shipping, other modules, including perception must be added to control architecture

Thanks for your attention!