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Ship`s machinery selection and electrical systems

2023-01-23

Contents

Introduction to ship machinery choice

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Design process and machinery choice

From a ship designer's point-of-view, the ship design process is holistic and iterative

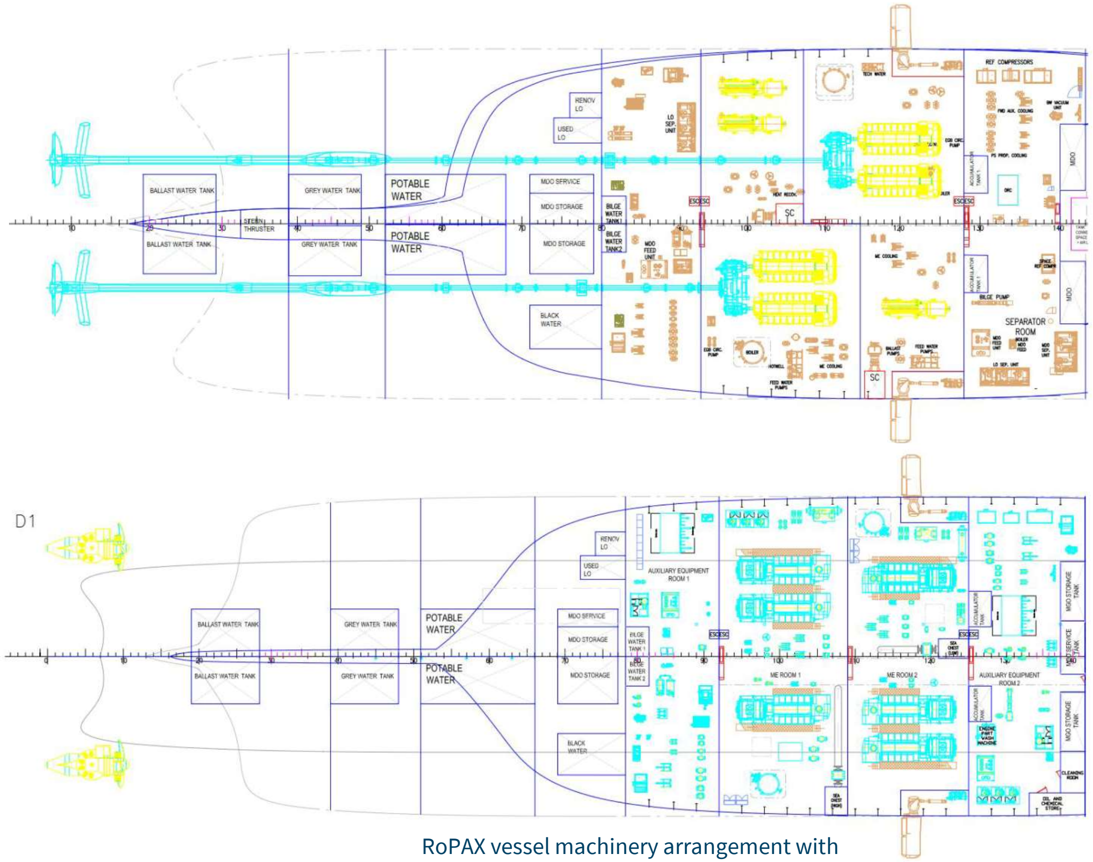
- The process is interdisciplinary and cross-company and the parts cannot be done in isolated silos
- Prevent sub-optimized solutions

The "decision process" can start even before the "design process" begins

- The owner commonly have certain preferences towards certain systems or vendors
- "No scrubbers", "Must have engine maker X", "No Chinese yard" etc.

Machinery concept choice factors

- To be considered:
  - Ship type/transport in general
  - Client business case
  - Operational profile
    - Relationship between various energy consumers
    - Port turnaround-time, maneuvrebility, accessible ports etc.
  - Holistic efficiency
    - Hydrodynamics
      - appendices, aft-ship form
      - Propulsion efficiency (hull-propeller-rudder-interaction)
    - Structures
    - Propulsion line efficiency
      - Diesel-electric vs. Mechanical propulsion etc.
    - Engine efficiency
    - ”Lay-out efficiency” → cargo capacity etc.



RoPAX vessel machinery arrangement with shaft lines and azimuth thrusters

Machinery choice, propulsion options

	Electric propulsion	Mechanical propulsion, 2-stroke	Mechanical propulsion, 4-stroke
Suitability	Ships having high electrical load, high manoeuvring needs, variable propulsion load.	Ships having low manoeuvrability needs, high propulsion power and long voyages.	Ships that have high manoeuvring needs and high propulsion power.
Typical propulsion options	Azimuthing propulsion motor or electric motor with shaft line.	FPP on shaft line, PTO.	CPP with reduction gear, PTO.
Pros	Number and power of engines can be selected so that load is in optimum level in all conditions. High efficiency for hotel load due to bigger (more efficient) engines. High manoeuvrability (Azimuth). Alternative power production in hybrid use.	Lowest losses on propulsion power. Can have PTO for hotel load.	Propulsion losses between electrical and 2-stroke, relatively good hotel with PTO.
Cons	High losses on electrical systems.	Less flexible, lower maneuverability.	Losses on reduction gear, less flexible on operation than electric propulsion.
Good to know	Number of engines selected so that the load would be usually close to 85%, in all conditions. Number of engines running in operation can vary.	Propeller rpm must match to engine rpm's. Engine must be selected (de-rated) so that it suits for propellers. Target load usually around 70%.	With reduction gear ratio the propeller and engine rpm`s can be matched. Usually target load around 85%.

Machinery choice and design process

During concept design the various alternatives are compared to each other on a principal level

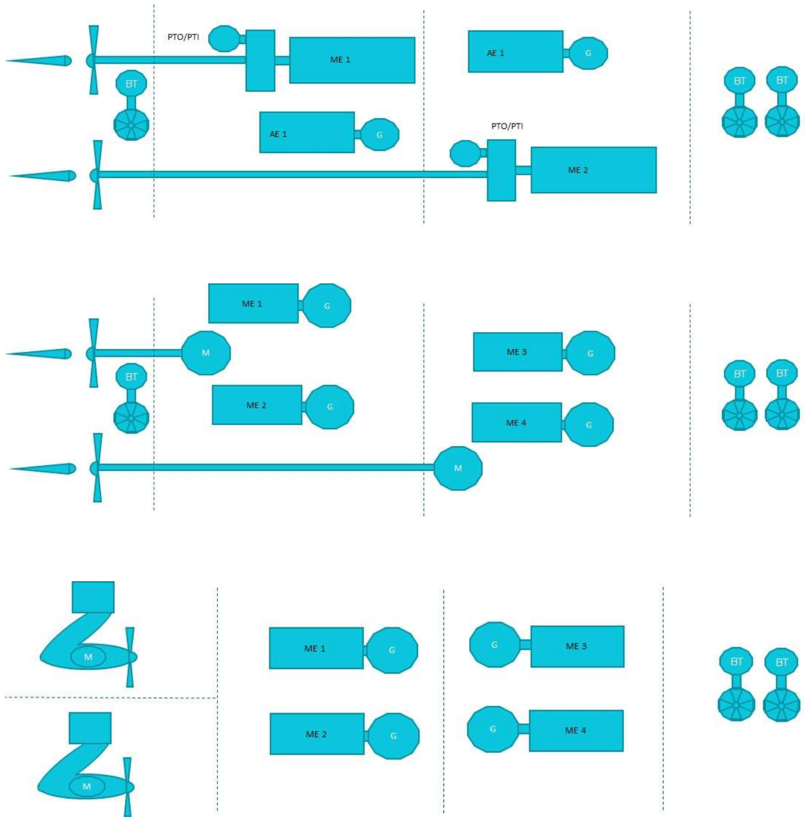
- Losses/efficiency of electrical transmission for propulsion + hotel included in the holistic evaluation
- Normally simplified total efficiency figures

It is possible to consider various system efficiency curves during energy modelling already at concept design phase

- It is easier to compare various layouts against each other than various makers of the same type of system against each other

Figure:

- ❑ Option A, Mechanical propulsion
- ❑ Option B, Diesel electric propulsion with shaft lines
- ❑ Option C, Diesel electric propulsion with azimuthing POD’s

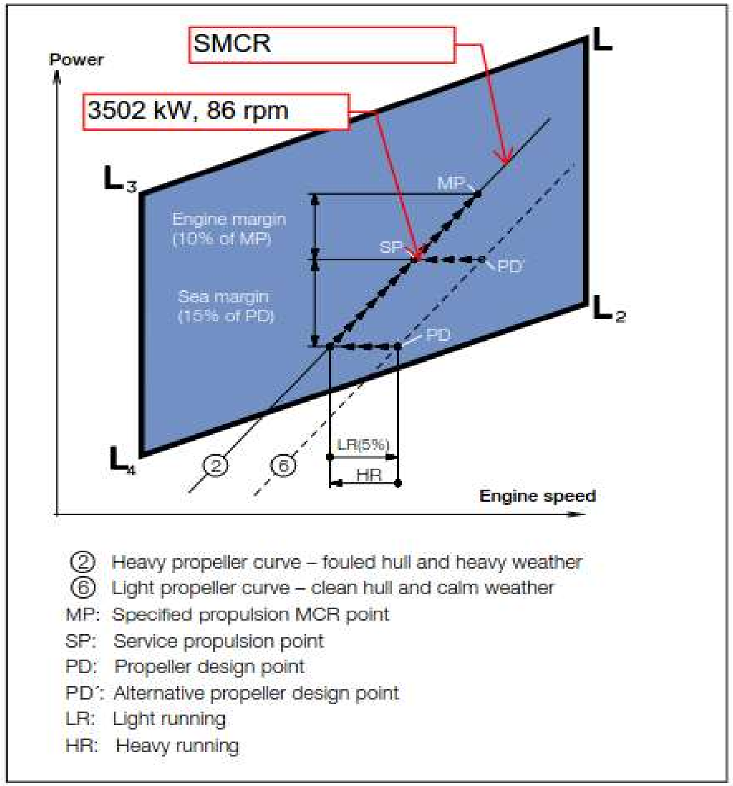


Makers

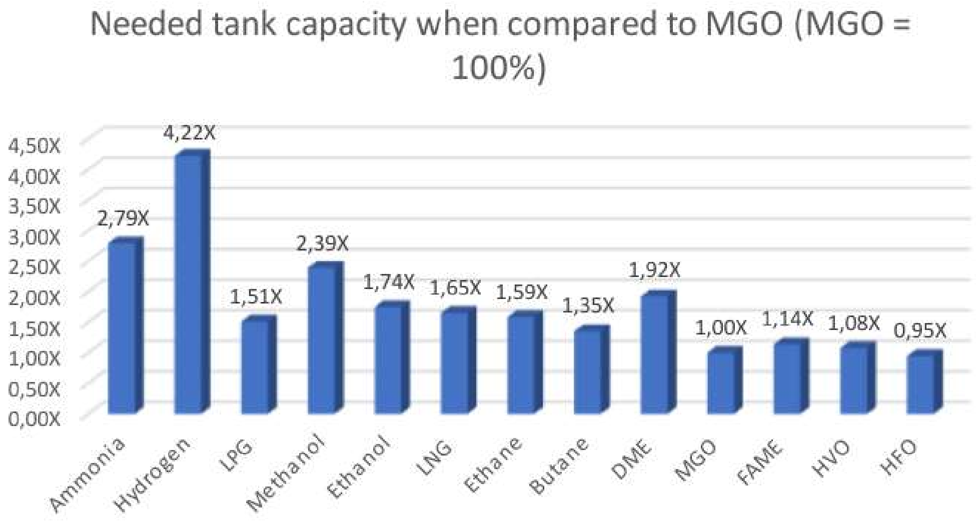
- MAN
  - 2-strokes, performance data to be found in:
  - https://www.man-es.com/marine/products/planning-tools-and-downloads/ceas-engine-calculations
- Win-GD
  - 2-strokes
  - https://www.wingd.com/en/engines/general-technical-data-(gtd)/
- Wärtsilä
  - 4-strokes
  - https://www.wartsila.com/marine/engine-configurator
- Mitsubishi, Bergen engines (gas and liquid fuel engines), Yanmar (typically aux generating sets)
- Gas tubines: https://www.geaviation.com/marine/systems
- Fuel cells:
  - PEM: Ballard, Hydrogenics/Cummins, Powercell
  - SOFC: Bloom, Convion
  - Etc.

Example of process when choosing a 2-stroke engine

- Steps in choice:
  - Power and RPM definition =>
  - Engine margin definition, for example 10%, =>
  - Max power (=SMCR) =>
  - SMCR RPM on propeller curve =>
  - Choosing the suitable engine =>
  - SMCR point =>
  - Specific fuel (oil) consumption (SFOC) and capacities with CEAS- or GTD-program etc.
- Usually, engine is coupled to fixed pitch propeller - > propeller rpm must meet engine rpm.
- Sea margin is added to power prediction (usually +15%).
- Engine is de-rated so that wanted rpm and power is met, target to be close L2-L4 line.
- Higher de-rating may lead to lower consumption but can increase CAPEX.
- Final propeller shall be lightened (light running margin usually 5-8%, leads to higher rpm than in design) in order not to exceed engine torque limits in any conditions.



Alternative fuels



Compared by fuel LHV, average values used from several sources

- Alternative fuels takes more space than conventional fuels.
- Usually, DF engines is selected so that diesel can be used as back up in case of malfunction / leakage.
- Fuel cells can be an option/hybrid option for combustion engines.
- Emission neutral fuels are more expensive than fossil fuels, which shortens the payback time of energy saving devices.

Electrical

Concept design phase, electric

Electrical design conceptual/initial phase studies

- Space reservation (general arrangement based)
- Dimensioning of electrical room/lockers, switchboard room
- Electric generation and propulsion type (machinery assist, e.g. electrical propulsion)
- Electrical distribution principles, short circuit currents estimation
- Main cable way and cable trunks reservation and principle routes
- Interpretation of a specific project rules

Rules and Regulations for Design

- IMO - Safety of Life at Sea (SOLAS)
- Classification Society, Flag state
- Other regulations (Panama, Suez rules etc.)
- Project specific rules, Yard`s instructions

Electrical installations shall be such that the safety of passengers, crew and ship, from electric hazards, is ensured.

Voltage level decision making

Voltage level decision making

- High voltage level usually selected acc. to short circuit current level (high currents)
- Generators individual/total power
- Network distribution/functional limitations
- Propulsion / system manufacturer`s information, short circuit current levels, main switchboards dimensioning & circuit breakers selection, cable sizes, shore connection voltage etc.
- Shipowners/yard´s instructions for selection
- Operational area (shore side facilities)

Voltage levels in ships:

- In Europe
  690V/50Hz, 400V/50Hz, 230V/50Hz
- In USA
  440V/60Hz, 230V/60Hz, 208V/120V/60Hz

Voltage	Installed Generator capacity	IEC 61892-2 / Norsok E-001	
		Genenerators	motor. Direct on line
11 kV	40 ... MVA	> 20MW	> 400 kW
6,6 kV	10 ... 60 MVA	4 - 20MW	> 400 kW
3,3 kV	7 ... 25 MVA	4-20MW	> 400 kW
690 V	...11 MVA	< 4MW	< 400 kW
450 V	...10 MVA		
400 V	...9 MVA		

Guidance for voltage decision making

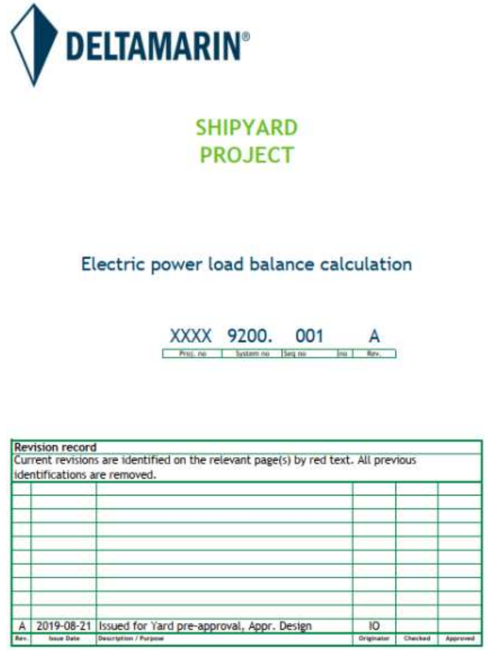
Electrical load balance

Electric load analysis

- Aim is to present capacity of ship`s electric generation with estimation of electric load in different operational scenarios
- Calculation is done for normal and emergency situation
- Main target of the document is to evaluate the required generators power demand in different operational scenarios

→ Load analysis in design phase should not be interpreted as ”normal average ship load”

- Experience is required for transforming electrical load balance figures to input for energy simulation model, for instance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SHIPYARD
PROJECT

Electric power load balance calculation

XXXX 9200. 001 A

Revision record
Current revisions are identified on the relevant page(s) by red text. All previous identifications are removed.

Rev.	Issue Date	Description / Purpose	Originator	Checked	Approved
A	2019-08-21	Issued for Yard pre-approval, Appr. Design	IO		

Electrical load balance

Electric load analysis

- Usually load balance is calculated only for summer period
- Principle of the document should always be same
- Example (summary sheet):

  - At Sea, Manoeuvring, Loading/Unloading, Emergency
- Emergency consumers:

  - SOLAS - Chapter II-1 - Part D - Electrical installations - Regulation 42 - Emergency source of electrical power in passenger ships

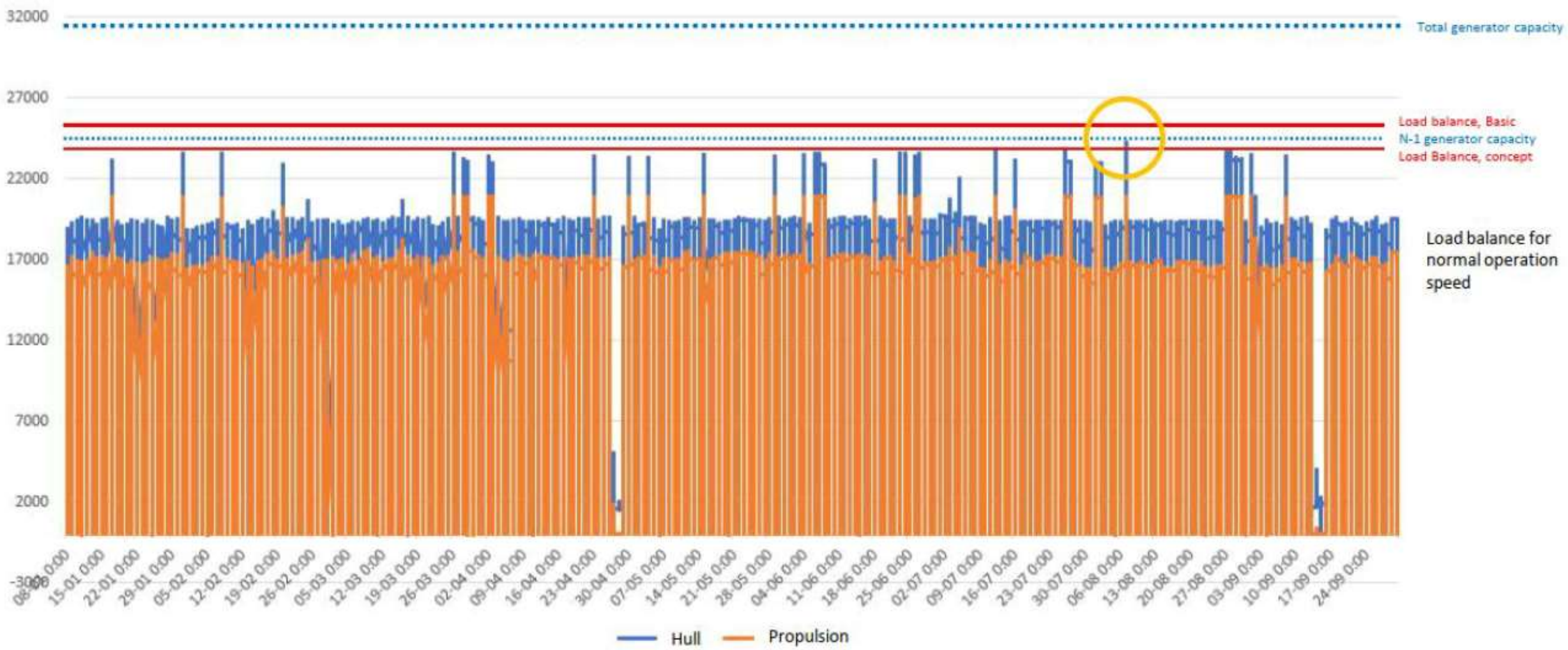
  - SOLAS - Chapter II-1 - Part D - Electrical installations - Regulation 43 - Emergency source of electrical power in cargo ships
- Notice, calculation for Safe Return to Port (SRtP) situation (passenger vessels)

CONSUMER	CONSUMER DATA	AT SEA		
Date:		TOTAL		
RESULTS All power values in kW Rev. 0		Notes:		
power at consumers	**10752**	**4701**		
- Trusters	1600			
Efficiency for thrusters	97,0 %			
- Propulsion Power	3000	3000		
Efficiency for Propulsion train	93,9 %	93,9 %		
- Ships consumer Load	6152	1701		
Average efficiencyfor for ship load	95,0 %	95,0 %		
(of which Non-essential load)		(530)		
ELECTRIC GENERATION		MG1-2		MG3-4
Generator capacity		1600		1600
Number of generators in use		2		2
GENERATORS TOTAL LOAD			4986	
GENERATOR LOADING		**78%**		**78%**
Generator effiency		96,0 %		96,0 %
ENGINES TOTAL LOADING			5194	
Engine capacity		1665		1665
Number of engines running		2		2
ENGINE LOADING		78%		78%
Number of generators stand-by				
Available generator capacity		707		707

	CONSUMPTION FOR GROUPS (at consumer)	N:o	ABS	Power	In use	COE	%
1	AUX .MACH. FOR PROPULSION	96	1221	205	59	0,17	4%
2	AUX .MACH. FOR SHIP	42	486	138	25	0,28	3%
3	HVAC and HEATING	54	1608	628	41	0,39	13%
4	GALLEY, LAUNDRY, WORKSH.	5	795	321	5	0,40	7%
5	CARGO, DECK AND HULL	53	1495	41	16	0,03	1%
6	LIGHTING	158	456	304	156	0,67	6%
7	NAVIGATION AND AUTOMATION	15	57	37	15	0,65	1%
8	SELECTIVE CATALYTIC REACTOR (SCR)	4	34	27	4	0,80	1%
9	BOW THRUSTER	2	1600				
10	PROPULSION MOTORS	2	3000	3000	2	1,00	64%
	TOTAL (At consumer)	431	10752	**4701**	323	0,44	100%

Example of electric balance summary sheet (at sea mode as principle)
“only indicative, as template needs to be modified for each project”

Ship real-life power consumtion vs. load analysis

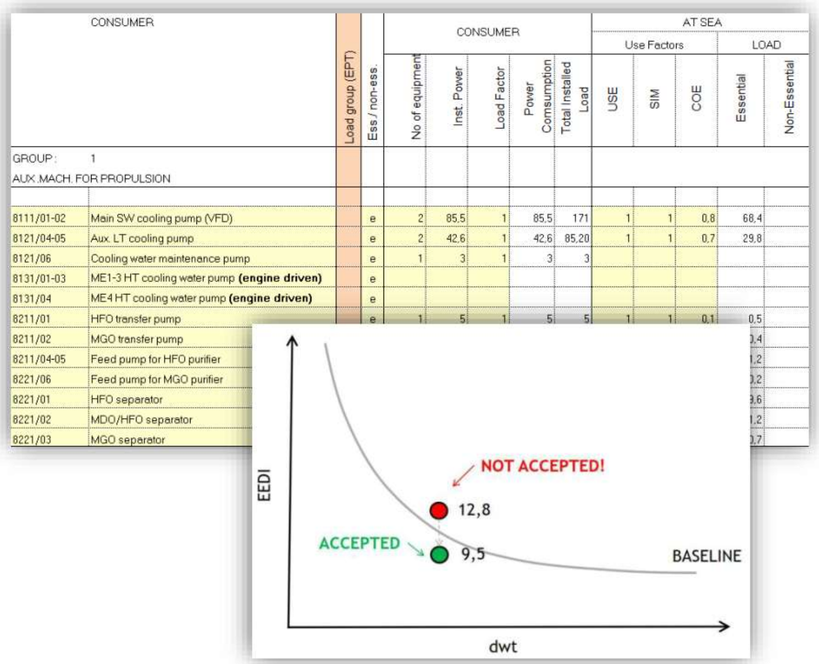


EEDI - EPT calculation

The objective of EEDI is to improve the energy efficiency of new ships, reducing CO2 emissions

- Auxiliary engine power (Pae) definition for EEDI
  - Pre-defined EEDI formula or Electric power table (EPT) calculation

- EPT calculation -> detailed consumer data
  - Consumers divided to load groups (from A to M)
  - Service factors (load, duty, time)
  - Electrical load analysis may be used as a basis for calculation



CONSUMER				CONSUMER					AT SEA				
									Use Factors			LOAD	
		Load group (EPT)	Ess / non-ess.	No of equipment	Inst. Power	Load Factor	Power Comsumption	Total Installed Load	USE	SIM	COE	Essential	Non-Essential
GROUP :	1												
AUX.MACH. FOR PROPULSION													
8111/01-02	Main SW cooling pump (VFD)		e	2	85,5	1	85,5	171	1	1	0,8	68,4	
8121/04-05	Aux. LT cooling pump		e	2	42,6	1	42,6	85,20	1	1	0,7	29,8	
8121/06	Cooling water maintenance pump		e	1	3	1	3	3					
8131/01-03	ME1-3 HT cooling water pump **(engine driven)**		e										
8131/04	ME4 HT cooling water pump **(engine driven)**		e										
8211/01	HFO transfer pump		e	1	5	1	5	5	1	1	0,1	0,5	
8211/02	MGO transfer pump											[illegible]	
8211/04-05	Feed pump for HFO purifier											[illegible]	
8221/06	Feed pump for MGO purifier											[illegible]	
8221/01	HFO separator											[illegible]	
8221/02	MDO/HFO separator											[illegible]	
8221/03	MGO separator											[illegible]	

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Power generation and distribution

Power generation and distribution

Common requirements

- Two independent electric power supply systems shall be arranged on board
    - Main network
    - Emergency network
  - In blackout situation the emergency generator starts and connect to network -> feeding consumers which are required to feed by Solas
- Generators e.g. stand-by generator to ensure power for propulsion, safety, minimum habitable conditions etc.
- Heavy consumers (not necessary in use at all times e.g. bow thruster), may require all generators to be on-line - dimensioning
- Redundant consumers are supplied from separate switchboard sections of motor control centers (MCC) according to requirements e.g. Safe Return to Port (SRtP) or Redundant Propulsion (RP)

Power generation and distribution

Main distribution selection

✓ Overall ship design shall give the criteria for distribution system

- Feasibility and concept design (e.g. ship type, operational aspect, route)
- Specification, rules and requirements
- The markets and prices, shipowners and global interest
- Machinery selection (e.g. propulsion & prime movers, fuel and heat systems)
- Redundancy requirements and safe operation (e.g. SRtP, RP)
- Electrical dimensioning (e.g. load, efficiency, voltage, short circuit current, total harmonic distortion)

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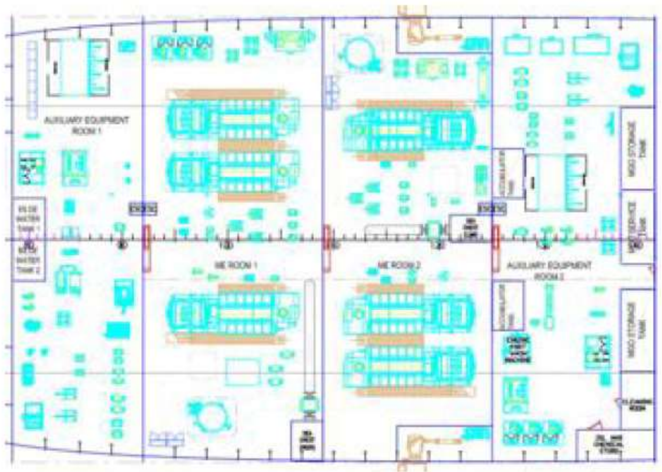
Power generation and distribution

Machinery selection relation to main electric distribution configuration

- Classification
- Redundancy requirements
- Propulsion (mechanical or electrical)
- Propeller type (CPP or FPP)
- M/E selection / type (speed, 2 or 4-stroke)
- Generators (shaft generators PTO/PTI, aux. generators)
- Emergency generator set
- Fuel type (HFO, MGO, DF, gas)
- Alternative power sources (e.g. batteries, fuel cells, solar)

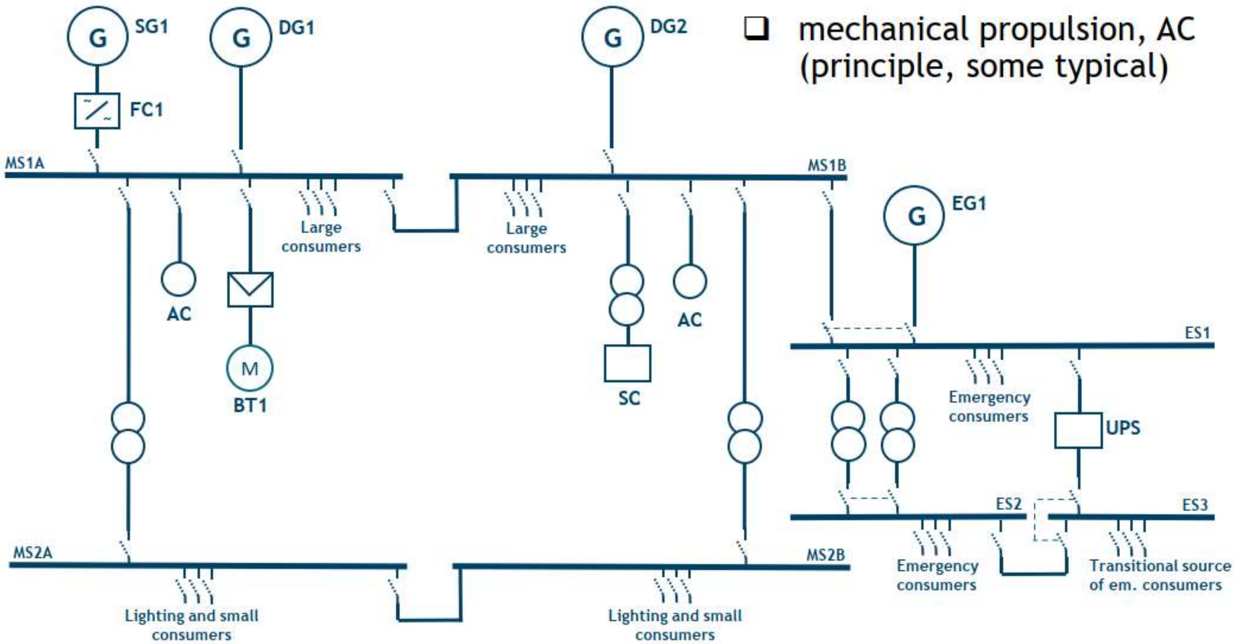


Power generation and distribution

Power generation and distribution
Abbreviations:

SG1 Shaft generator
FC1 Frequency converter
DG1 Auxiliary generator
DG2 Auxiliary generator
EG1 Emergency generator
BT1 Bow thruster
MS1A/MS1B Main switchboard
MS2A/MS2B Lighting switchboard
SC Shore connection box
ES1-3 Emergency switchboard
UPS Uninterrupted power source

- mechanical propulsion, AC (principle, some typical)



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Power generation and distribution

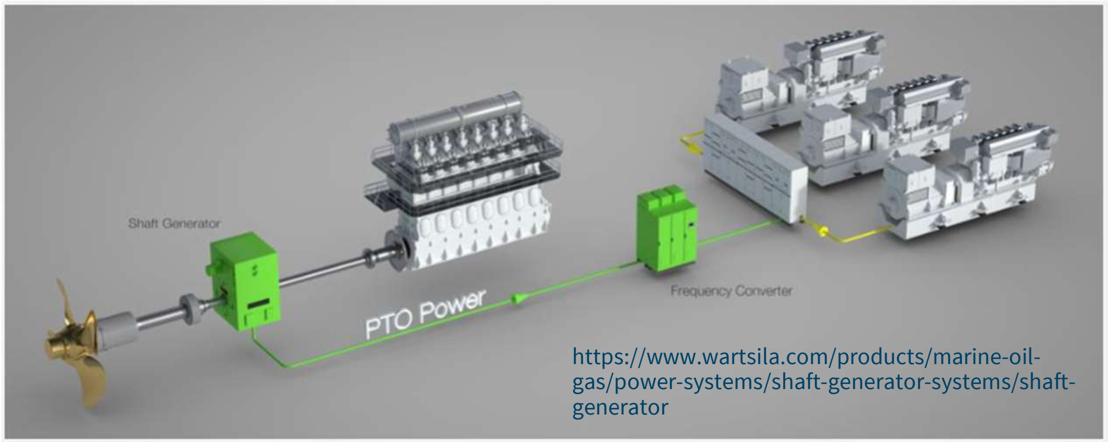
Power take off (PTO)

- Low speed main engine

The shaft generator is installed in the shaft line between the low-speed main diesel engine and the propeller or tunnel gear unit between low-speed main diesel engine and the propeller

- Medium speed main engine

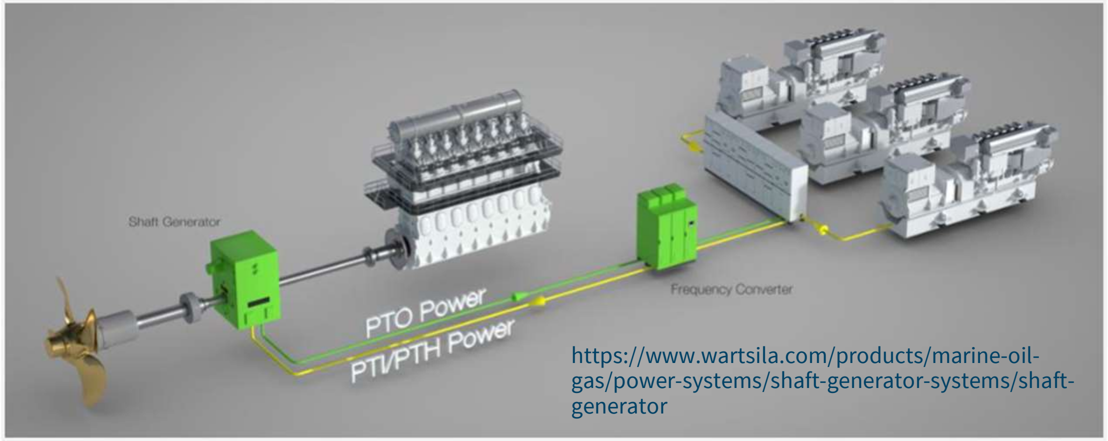
The shaft generator is operated via a power take-off (PTO) by a reduction gear which is arranged between the main diesel engine and the propeller



Power generation and distribution

Power take in (PTI)

- Booster propulsion operation parallel to the main engine to enlarge the propulsion power and the ship's speed
- "Take me home" propulsion operation as emergency propulsion drive without main engine in case of a malfunction of the main engine (main engine has to be declutched from the propeller shaft)



https://www.wartsila.com/products/marine-oil-gas/power-systems/shaft-generator-systems/shaft-generator

Power generation and distribution

Reduction gear

- Reduction gear configuration shall be check when considering shaft generator use
  -> PTI/PTO suitability (primary/secondary/secondary with clutch)

1 Propulsion only
2 Propulsion + PTO
3 Propulsion + PTI
4 PTI only
5 PTO only

TECHNICAL DATA

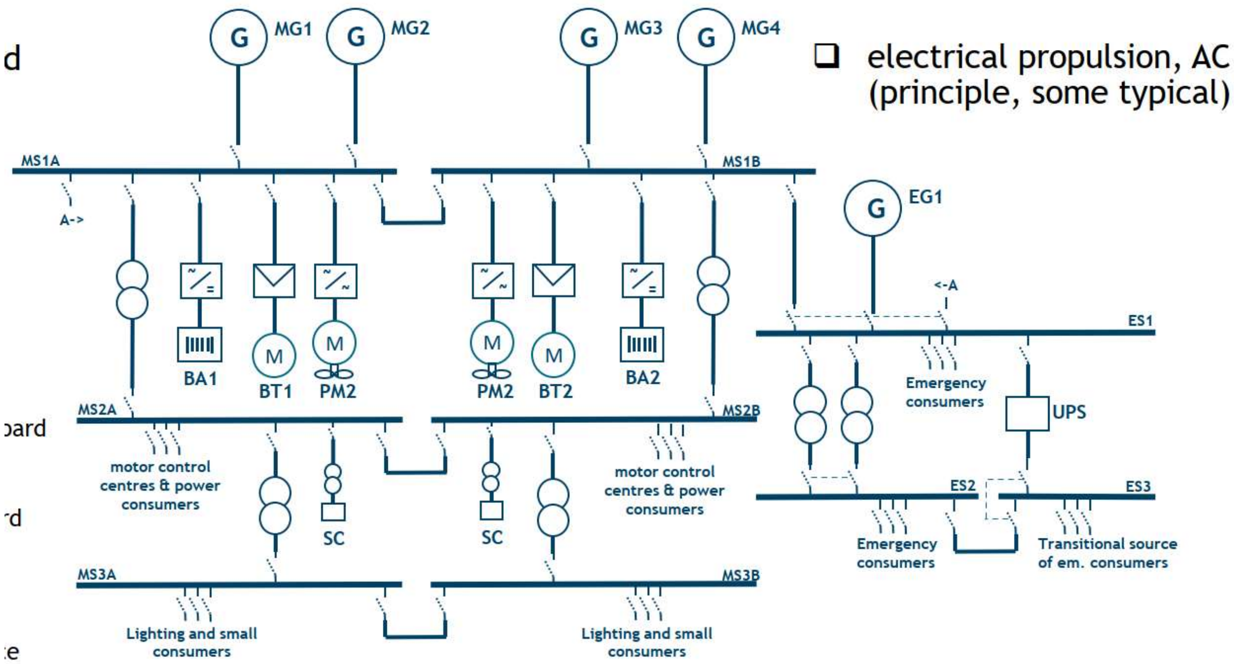
Mode no.	Descr.			Gear configuration	Gear configuration
Mode no.	Descr.	No PTI/PTO	Primary PTI/PTO	Secondary PTI/PTO	Secondary PTI/PTO w/clutch
Mode no.	Descr.	-	P or KP	S or KS	SC or KSC
1	Propulsion only	OK	Will spin generator	Will spin generator	OK
2	Propulsion + PTO	Not possible	OK	Check power system design and DP requirements	Check power system design and DP requirements
3	Propulsion + PTI	Not possible	OK	OK	OK
4	PTI only	Not possible	Not possible	OK	OK
5	PTO only	Not possible	OK	Not possible	Not possible

Rolls Royce example of different configuration

Power generation and distribution

Power generation and distribution
Abbreviations:

Abbreviations:
MG1-4 Main generator
PM1-PM2 Propulsion motor
BT1-2 Bow thruster
EG1 Emergency generator
BA1-2 Battery storage
MS1A/MS1B Propulsion switchboard
MS2A/MS2B Main switchboard
MS3A/MS3B Lighting switchboard
SC Shore connection box
ES1-3 Emergency switchboard
UPS Uninterrupted power source



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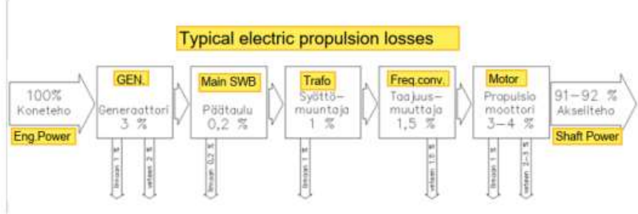
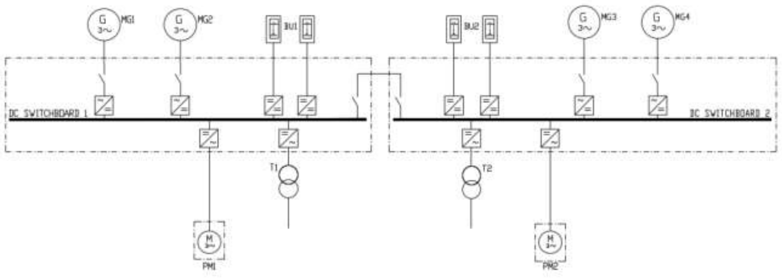
Power generation and distribution

DC distribution network

- Engines may operate all the time in optimal curve and generators can run with variable speed
- Extension of DC power sources or energy storages to DC-busbar (batteries/fuel cells/solar panels/etc.)
- Total space requirement (integrated propulsion switchboard and frequency converter)
- Efficiency comparison (AC or DC, propulsion package Vendors)



❑ Propulsion train electrical losses (some typical)



❑ Principle of Centralized-DC distribution

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Power generation and distribution

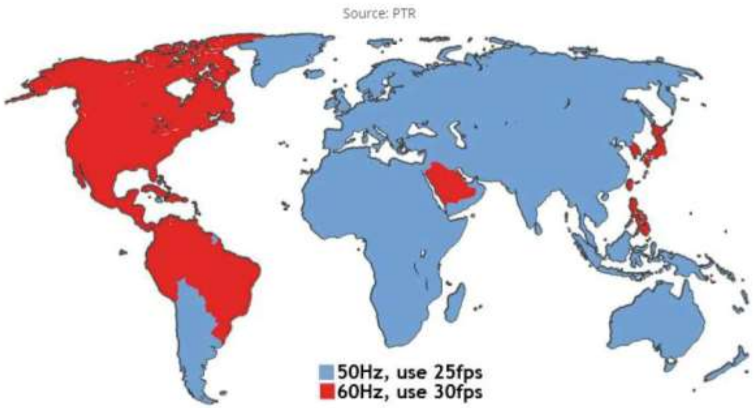
Energy Storage System

- Energy storage systems designed for marine operation can be installed to support vessel hybrid or fully electric power production depending on selected configuration.
- Items to notice: ship operation profile, route, ship type etc.
- In general, battery storage configuration will include parallel connected battery packs, depending on the power and energy requirements.
- Specific additional functions for example blackout prevention (powering and connecting battery banks to dead busbar), UPS function (continuation of operation during external power failure) or other functions may be included.
- Battery charging to be taken into account e.g. with ship generators at transit, shore connection.
- Interface to IAS/PMS.

Power generation and distribution

Shore Connection

- Shore power connection is arranged to provide electrical power from shore power grid to the ship.
- Shore power technology is provided to reduce air pollution and save fuel by allowing to stop the use of ship’s own engines. Shore power can be used for charging energy storage batteries.
- Shore connection voltage/frequency varies between different ports and ships system should be selected according to port facilities.
- Electric load profile will be based on situation where the necessary electric loads of the vessel shall be covered with shore connection from the shore side.
- Interface to IAS/PMS.



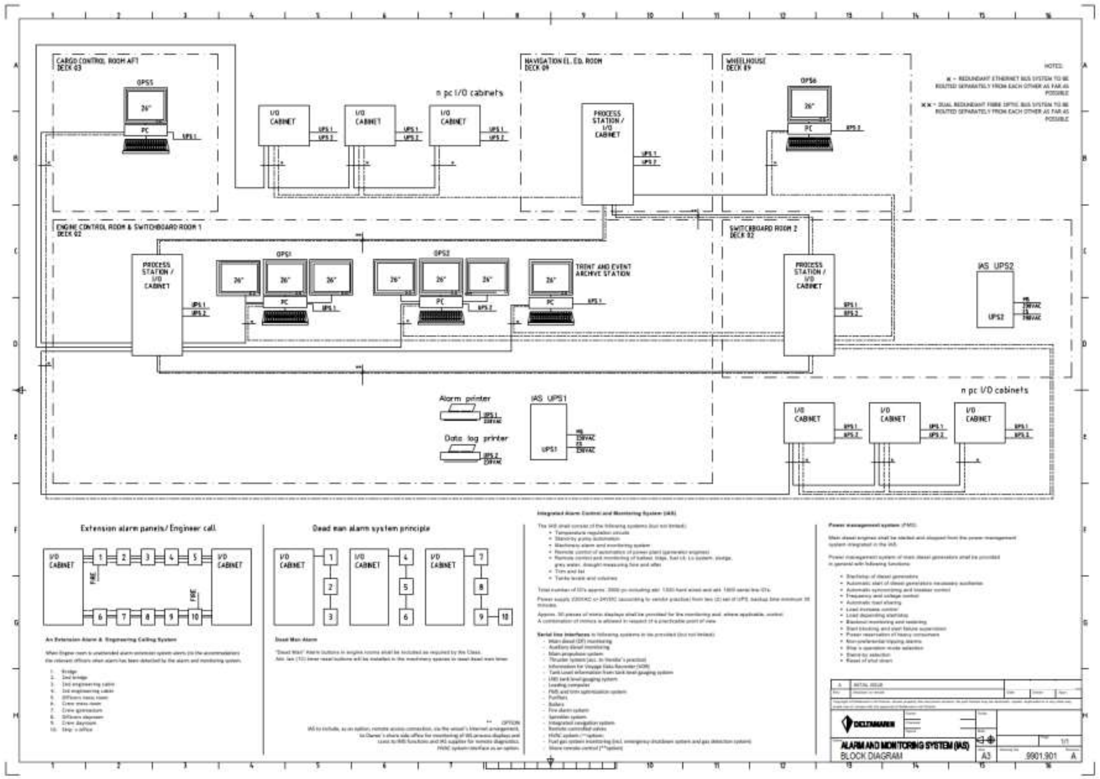
- Generally used frequencies, world map.

Machinery automation

Machinery Automation

Integrated Automation System
(IAS)

- Control and supervision to be arranged so that the propulsion plant is capable of being operated under normal sea-going condition
- To meet classification requirements
- Normal operations shall be monitored and controlled from the ECR or periodically from wheelhouse when machinery spaces are unattended



❑ Automation Monitoring System, Block Diagram (some typical)

Machinery automation

Integrated automation system (IAS)

- Amout of I/O`s (input/output) is one way to describe ship`s automation system size and cost
  - (e.g. tanker abt. 2000 I/O`s or cruiser 10000 - 30000 I/O`s)

- System equipment and configuration (acc. to system vendor`s practice)
  - I/O cabinets and –modules
  - Process stations
  - Communication data bus
  - Operation stations
  - Sensors and field actuators

- Engine control room (ECR) shall be arranged close to engine room

Machinery automation

Power management system (PMS)

- Controls power generation (generators) and power distribution (main switchboards) to secure enough available power for propulsion and manoeuvring, to reduce a risk of a bad performance and blackouts
- PMS system may be integrated in automation system
- Emergency diesel generator shall have an independent control system
- Interfaces to ship systems

Power management system of main diesel generators shall be provided in general with following functions:

- Start/stop of diesel generators
- Automatic start of diesel generators necessary auxiliaries
- Automatic syncronizing and breaker control
- Frequency and voltage control
- Automatic load sharing
- Load increase control
- Load depending start/stop
- Blackout monitoring and restoring
- Start blocking and start failure supervision
- Power reservation of heavy consumers
- Non-preferential tripping alarms
- Ship`s operation mode selection
- Stand-by selection
- Reset of shut down

❑ PMS function (some typical), mainly standardized functions

Machinery automation

Operation Control Station (OPS) mimics

- OPS mimics, remote supervision/surveillance and remote-control display of ship machinery systems
- Remote control e.g. machinery pumps and fans, power network main breakers etc.
- Surveillance to ensure the safety of the passenger crew and ship operation

❑ Amount of mimics shall be estimated during conceptual phase (specification, level of surveillance, main machinery/engines and propulsion type, ship systems etc.)

Machinery automation

Instrumentation

- Piping and instrumentation (PID) diagrams & I/O list & mimics are in interconnection with each other
- Co-operation together between automation & machinery disciplines
- Scope shall be determined e.g. Class requirements (class notation), ship`s specification, ship systems and equipment etc.

❑ Part of I/O list as principle (some typical).

Electrical equipment

Electrical equipment

Main electric equipment in machinery spaces

How to locate? -> Base information

- Rules and requirements, classification, machinery arrangement, hazardous area plan, fuel system, fire and gas, ship`s type, propulsion type etc.
- Machinery arrangement (co-operation between machinery and electric)

Considerations,

- Weight and dimensions (preliminary data, references)
- Installation method to the surface
- Hauling into the space/room
- Maintenance spaces
- Other specific instructions

Electrical equipment

Dimensional data and weight information

- Information from other disciplines (general, machinery, HVAC etc.)
- Arrangement drawings (GA, MA)
- Power generation and distribution, single line diagram (main equipment)
- Reference projects
- Input from Owner/Yard
- Vendor`s material

-> List of electrical equipment

❑ Part of electric equipment list

Electrical equipment

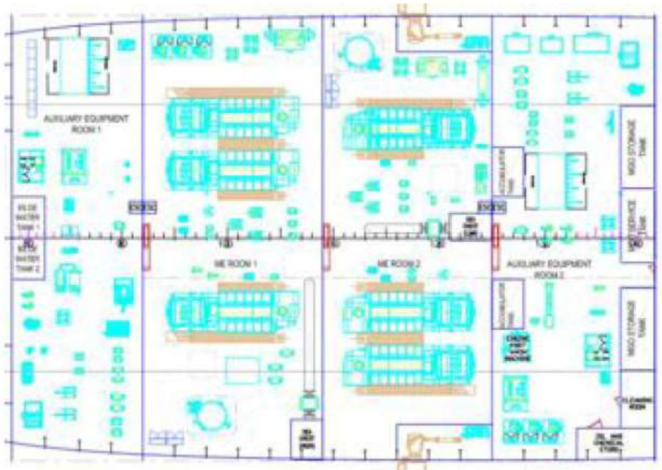
Azimuthing POD propulsion, main equipment:

- Propulsion transformers (MSB or converter room)
- Propulsion frequency converters (converter room)
- Propulsion motors (outside the hull at P- and SB side)
- BR breaking resistors (converter room)
- CAU cooling air units (POD room)
- SRU slip ring unit (POD room)
- UPS units for power switchboard and propulsion control (MSB room)
- PCU propulsion control unit (converter room)
- SD steering drives (POD room)
- AIU azipod interface unit (POD room)
- Propulsion and steering remote and local control system components (POD, converter room, Bridge, ECR)
- POD Auxiliary mechanical systems
- Azipod data transmission & remote diagnostics cabinets

Electrical equipment

M/E and auxiliary equipment rooms

- Machinery supplier`s electrical cabinets
- Frequency converters for aux. machinery
- Motor control centres (MCC)
- Ventilation motor control centres (VMCC)
- Separate starters
- Power distribution boards
- Normal and emergency lighting switchboard
- Other distribution switchboard
- Other system cabinets (e.g. I/O cabinets)



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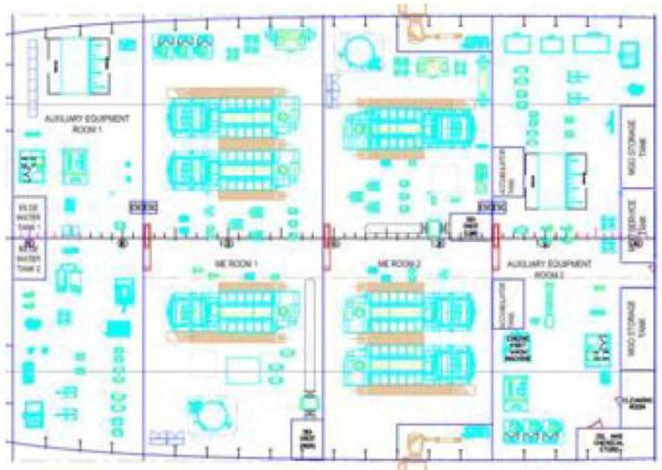
Electrical equipment

Main switchboard rooms

- Machinery supplier`s electrical cabinets
- Freguency converters
- Motor control centres (MCC)
- Ventilation motor control centres (VMCC)
- Transformers
- Distribution boards
- Alarm system control boxes
- Automation cabinets (process and I/O distribution)



Electrical equipment

Propulsion converter rooms

- PFC Propulsion frequency converter
- PCU Propulsion control unit
- BR Braking resistor
- PT Propulsion transformer
- PB power distribution board

- [ ] Part of GA (POD converter rooms)

Electrical equipment

Propulsion battery rooms

- Energy storage battery package
  - Dedicated converters and transformers are located usually in electrical switchboard / transformer rooms.
  - Ship`s operation profile (for dimensioning of battery storage system)

Electrical equipment

Engine control room (ECR)

- Engine control desk
- Distribution boards
- Machinery automation UPS
- Automation operation stations
- Automation cabinets (I/O units, process station)
- Other machinery cabinets (ME I/O units, communication PA/GA, safety e.g. CCTV surveillance, fire fighting drencher etc.

- Example of engine control room layout (some typical)