DITEN Department of Electrical, Electronic, Telecommunications Engineering and Naval Architecture
Polytechnic School, University of Genoa

IEES – Intelligent Electric Energy Systems Laboratory

IL SISTEMA ELETTRICO A BORDO DELLE GRANDI NAVI

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Movimenti di una nave

I movimenti di una nave sono interpretabili come quelli di un corpo rigido a sei gradi di libertà: tre traslazioni e tre rotazioni.

Le traslazioni secondo l'asse longitudinale (AVANZO) e trasversale (DERIVA) insieme alla rotazione intorno all'asse verticale (Angolo di Prora) costituiscono il processo di navigazione[2] ed il loro controllo è indicato come GOVERNO.

Il governo della nave è ottenuto mediante spinte realizzate da organi appunto di governo[3], che possono essere attivi, come le eliche, o passivi, come i timoni, che sfruttano l'interazione con i primi.

Sistemi di Propulsione sono gli organi di governo attivi, cioè che producono spinte applicate alla nave.

Per realizzare il governo occorre che la spinta sia regolabile:

- in intensità
- nel senso della direzione (INVERSIONE)
- nell'azimut direzionale (angolo rispetto al Nord).

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Motore primo

Motore Primo trasforma in meccanica un'altra forma di energia; la regolazione della potenza meccanica è ottenuta variando la portata di un fluido motore:

- Motore Elettrico (ME): il fluido motore è la corrente elettrica I ottenuta da una sorgente ipotizzata a tensione costante V
- Turbina a Vapore (TV): il fluido è vapor d'acqua prodotto da caldaie a combustibile nucleare, fossile o a recupero di energia[4]
- Turbina a Gas (TG): il fluido è un derivato liquido o gassoso di combustibili fossili
- Motore Diesel (D), lento medio o veloce: il fluido è un derivato dei combustibili fossili
- Combinazione dei Precedenti (vedi Appendice al Cap 1 per la classifica NATO).

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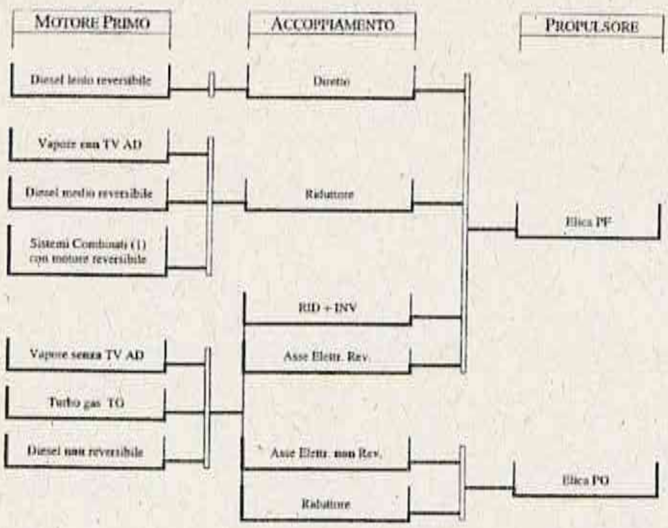
Soluzione con asse meccanico



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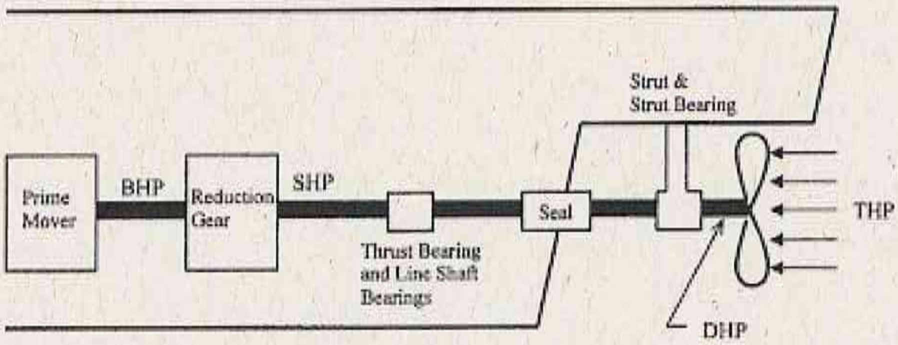
Soluzione asse meccanico tradizionale



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Soluzione asse meccanico tradizionale

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Soluzione asse meccanico tradizionale

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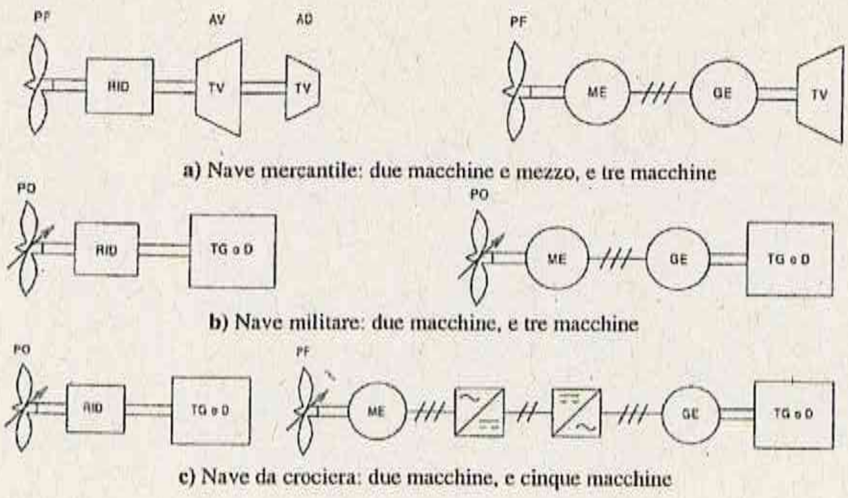
Soluzione asse elettrico



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Motivazione AE

Quando le alternative sono possibili, l'adozione dell'AE deve essere motivato da vantaggi, tali da sfruttare al massimo le differenze intrinseche tra AE e asse meccanico, che riguardano:

- l'ubicazione a bordo dei motori primi (gruppi elettrogeni) è svincolata da quella degli assi propulsivi;
- la velocità di rotazione dei motori primi può essere diversa e indipendente da quella degli assi;
- i cavi elettrici sostitutivi degli assi meccanici consentono il collegamento di qualunque elettrogeno a qualunque motore propulsivo;
- il frazionamento di potenza dei motori primi è indipendente da quello dei motori propulsivi.

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Motivazioni AE

I motivi che possono indurre a considerare l'adozione dell'AE sembrano principalmente tre.

i) Riduzione della potenza totale dei motori primi da installare a bordo.

La convenienza è tradizionalmente indicata quando la potenza elettrica dei servizi ausiliari di bordo (SA) supera il 40% di quella propulsiva, senza contemporaneità. Questa condizione si verifica per navi mercantili speciali (trivelle, posacavi, lavori subacquei, lavorazione del pescato) e più recentemente per navi da crociera gestite su percorsi che rendano non contemporanei la richiesta di potenza propulsiva e alberghiera.

ii) Esigenza di andature flessibili.

Si richiede alla piattaforma di variare in continuazione spinta e velocità (come per i rompighiaccio) oppure mantenere continuativamente andature molto diverse dal posizionamento dinamico al rimorchio con tiri e velocità diverse fino alla navigazione libera (come per navi da ricerca, ma anche cacciamine)

iii) Riduzione della vulnerabilità propulsiva.

Si richiede alla piattaforma di mantenere capacità di governo in caso di danno o avaria a uno o più componenti del sistema propulsivo. Questo caso si applica ad unità militari, piattaforma off-shore in condizioni meteo-marine estreme, ma anche alle navi mercantili per carichi pericolosi (sono classificati IM01 e 2).

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Motivazioni AE

Ciascuno dei motivi elencati suggerisce di considerare la PE, ma la reale convenienza si ottiene se è valido più di un motivo o possono essere soddisfatte ulteriori esigenze, tra queste sono riportate:

- riduzione dei vincoli costituiti da volume e posizione dell'AM convenzionale a vantaggio del carico e/o della funzionalità di missione;
- eliminazione del riduttore a ingranaggi e del suo rumore per motori primi a turbine;
- solo per AM a vapore, eliminazione della turbina di marcia AD e disponibilità AD della piena potenza (fig. 1.3a);
- frazionamento dei motori primi (elettrogeni) per ottenere il massimo rendimento in condizioni operative diverse;
- aumento della disponibilità di potenza elettrica ai servizi vitali ausiliari;
- semplificazione della condotta con più elevato grado di automazione e riduzione del personale;
- funzionamento dei motori primi a giri costanti con aumento del rendimento e riduzione della manutenzione.

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Motivation

- **Electrical installations are present in any ship**, from powering of communication and navigation equipment, alarm and monitoring system, running of motors for pumps, fans or winches, to high power installation for electric propulsion.
- The concept of electric propulsion is not new, the idea originated more than 100 years ago. However, with the possibility to **control electrical motors with variable speed in a large power range** with compact, reliable and cost- competitive solutions, the use of electrical propulsion has emerged in new application areas during the 80's and 90's.

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Motivation of EP

- Electric propulsion with gas turbine or diesel engine driven power generation is used in hundreds of ships of various types and in a large variety of configurations. Installed electric propulsion power in merchant marine vessels was in 2002 in the range of 6-7 GW, in addition to a substantial installation in both submarine and surface war ship applications.
- By introduction of **azimuthing thrusters and podded thrust units**, propulsion configurations for transit, maneuvering and station keeping have in several types of vessels merged in order to utilize installed thrust units optimally for transit, maneuvering and dynamically positioning (**dynamic positioning - DP**).

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Motivation of EP

- At present, electric propulsion is applied mainly in following type of ships:
  - Cruise vessels,
  - ferries,
  - DP drilling vessels,
  - thruster assisted moored floating production facilities, shuttle tankers, cable layers, pipe layers, icebreakers and other ice going vessels, supply vessels, and war ships.
- There is also a significant on-going research and evaluation of using electric propulsion in new vessel designs for existing and new application areas.

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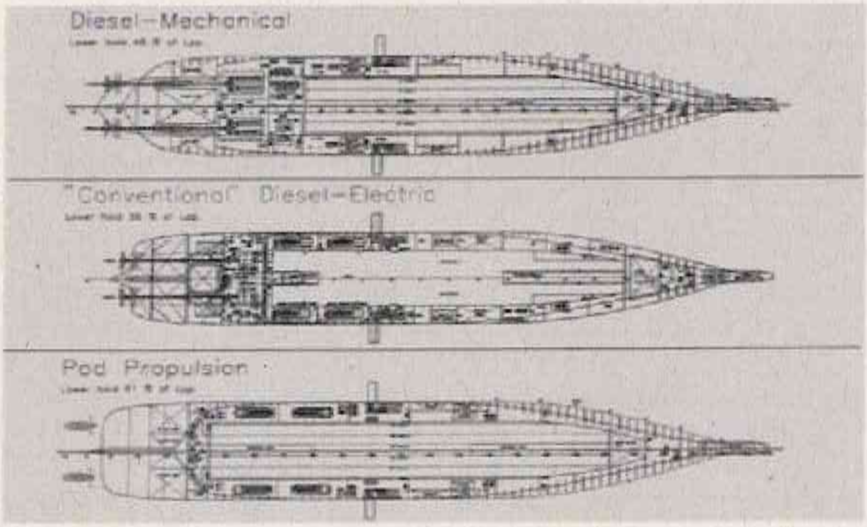
EP



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Advantages of EP

- Improved life cycle cost by **reduced fuel consumption and maintenance**, especially where there is a large variation in load demand. E.g. for many DP vessels a typically operational profile is equally divided between transit and station keeping/maneuvering operations.
- **Reduced vulnerability to single failure** in the system and possibility to optimize loading of prime movers (diesel engine or gas turbine).
- Light high/medium speed diesel engines.
- Less space consuming and more flexible utilization of the on-board space increase the payload of the vessel,

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Advantages of EP

- **Flexibility in location of thruster devices** because the thruster is supplied with electric power through cables, and can be located very independent on the location of the prime mover.
- Improved maneuverability by utilizing azimuthing thrusters or podded propulsion.
- **Less propulsion noise and vibrations** since rotating shaft lines are shorter, prime movers are running on fixed speed, and using pulling type propellers gives less cavitation due to more uniform water flow.

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Disadvantages of EP

- **Increased investment costs.** However, this is continuously subject for revisions, as the cost tends to decrease with increasing number of units manufactured.
- **Additional components** (electrical equipment – generators, transformers, drives and motors/machines) between prime mover and propeller increase the transmission losses at full load.
- For newcomers, a higher number and new type of equipment requires different operation, manning, and maintenance strategy.

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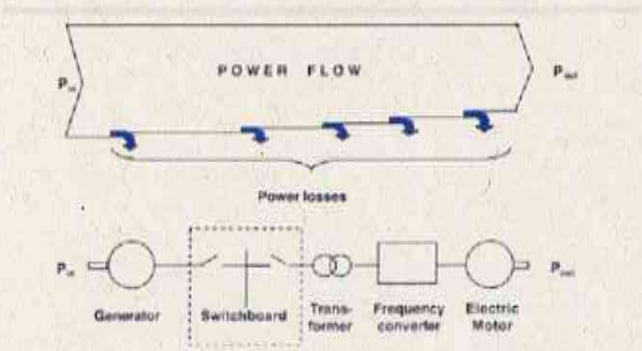
Power Flow and Power Efficiency



- In any isolated power system, the amount of generated power must be equal to the consumed power including losses.
- The prime movers, e.g. diesel engines or gas turbines, supply a power to the electric generator shaft. The electric motor, which could be the propulsion motor, is loaded by a power from its connected load. **The power lost** in the components between the shaft of the diesel engine and the shaft of the electric motor is mechanical and electrical losses which gives heat and temperature increase in equipment and ambient.

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Power Efficiency

- For each of the components, the electrical efficiency can be calculated, and typical values at full (rated) power are:
  - generator: η = 0.95-0.97,
  - switchboard: η = 0.999,
  - transformer: η = 0.99-0.995,
  - frequency converter: η = 0.98-0.99,
  - electric motor: η = 0.95-0.97.
- Hence, the efficiency of a diesel electric system, from diesel engine shaft, to electric propulsion motor shaft, is normally between **0.88 and 0.92 at full load**. The efficiency depends on the **loading of the system**.

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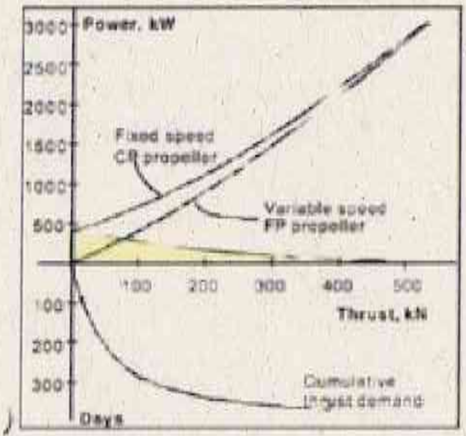
Power Efficiency

- Since the additional components between the prime mover and the propeller shaft in a diesel electric propulsion system contributes to a total of approximately 10% losses, the fuel savings potential is not due to the electrical component.
- One must regard the hydrodynamic efficiency of a speed controlled propeller compared to a fixed speed controllable pitch propeller (CPP), and the fuel efficiency of the prime mover when installed in a diesel electric system with constant speed and high loading, compared to in a mechanical propulsion system with strongly varying load.
- The differences may be significant, especially on low thrust operations as DP and maneuvering.



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Historical Overview of Electric Propulsion

- After the rather experimental applications of battery driven electric propulsion at the end of the 19th century took place in Russia and Germany, the first-generation electric propulsion was taken into use in the **1920**'s as a result of the strong competence of reducing transatlantic crossing times for passenger liners. At that time, the high propulsion power demand could only be achieved by turbo-electric machinery. "**S/S Normandie**" was one of the most renowned.

- Steam turbine generators provided electric power that was used to drive the 29 MW synchronous electrical motors on each of the four screw shafts. The rotational speed was given by the electrical frequency of the generators. The generators would normally run one propulsion motor each, but there were also possibility for feeding two propulsion motors from each generator for cruising at lower speeds.

- With the introduction of high efficient and economically favorable diesel engines in the middle of the 20th century, steam turbine technology and electric propulsion more or less disappeared from merchant marine vessels until the 1980's.

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Historical Overview of Electric Propulsion

- The development of variable speed electric drives, first by the AC/DC rectifier (Silicon Controlled Rectifier – SCR) in the 1970's and the AC/AC converters in the early 1980's enabled the power plant based electric propulsion system, which is typical for the second-generation electric propulsion.

- A fixed voltage and frequency power plant consisting of a number of generator-sets feeding to the same network was supplying the propulsion as well as the hotel and auxiliary power. The propulsion control was done by speed control of the fixed pitch propellers (FPP).

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Historical Overview of Electric Propulsion

- These solutions were firstly used in special vessels like survey ships and icebreakers, but also in cruise vessels. **"S/S Queen Elizabeth II" was converted to electric propulsion in the mid 1980's**, and later followed the Fantasy and Princess class cruise vessels, several DP vessels, and shuttle tankers. Notice that in direct driven diesel propulsion the thrust is normally controlled by a hydraulic system varying the propeller pitch angle. This is denoted as controllable pitch propellers (CPP).

- **Podded propulsion was introduced in early 1990's where the electric motor is installed directly on the fixed pitch propeller shaft in a submerged, rotatable pod.** While this concept was originally developed to enhance the performance of icebreakers, it was early found to have additional benefits on hydrodynamic efficiency and maneuverability.

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Historical Overview of Electric Propulsion

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Passenger Vessels – Cruise Ships and Ferries

- Passenger vessels, cruise ships, and ferries have very high requirement for on-board comfort regarding noise and vibration. In addition, the reliability and availability is very critical for the safety of the passengers and the vessel. Consequentially, electric propulsion was early evaluated to be beneficial and taken into use.
- The list of cruise vessels with electric propulsion is today long and increasing.
- As the environmental concern is increasing, the requirements of reduced emission, spill, and damages on coral reefs by anchoring of the cruise vessels are increasing. This will increase the need for electrical propulsion and podded propulsion in the cruise market even more.

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Passenger Vessels – Cruise Ships and Ferries

- The same restrictions and tax penalties for gas emissions (COx, Nox and Sox) have resulted in that several recent new buildings of ferryboats for fjord and strait crossing have been equipped with electric propulsion.
- The propulsion power varies with the size of the vessel, from some few MW for smaller ferries up to 30-40 MW for large cruise liners. The hotel load can be a significant part of the total power installation, for a large cruise liner typically in order of 10-15 MW.

LE NAVI

- Cruise Ships