UDC: 623.8:621.314.52(047.3)=20
COSATI: 13-10, 10-01

Electric drives of contemporary battleships

Zoran Nikolić, PhD (Eng)[1)]
Radoslav Nikolić, MSc (Eng)[2)]

This paper shows electric power transmission on battleships as a result of the latest technology developments. It also considers the AES (All Electric Ship) concept on battleships. It describes modern electrically driven battleships, i.e. gives details of electric drive systems from electric power production to ship propeller drives as well as some advantages of electric drive system of ships' propellers.

Key words: **battleship, electric drive, POD drives, cycloconverter, inverter.**

Introduction

ALTHOUGH the first electric propulsion was practically implemented in 1938 on the Neva river when M. Jakobi [1] drove a boat with a primitive electric motor for a short while and with 14 people on board, the electric drive was restricted to rivers and lakes for drive of boats and small ships until the end of the 19th century. During this period a development of submarine drive emphasized the significance of electric propulsion. In 1900 Nikola Tesla predicted electric drive on large ships in the Century Magazine, and two years before that he had described his well-known remotely controlled boat.

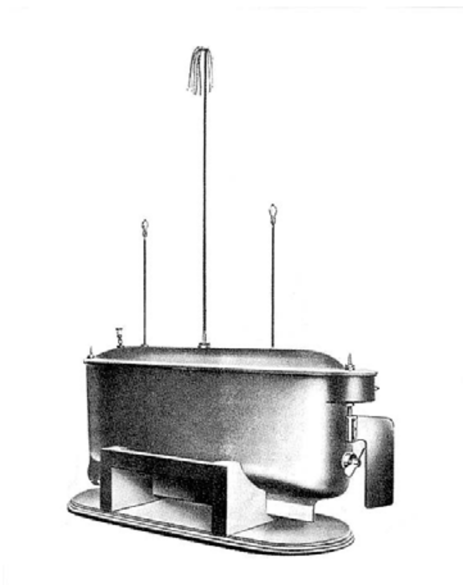

Figure 1. Model of a remotely controlled electric boat in Tesla's museum in Belgrade

In 1917 Tesla wrote about battleship electric drive [2]: "According to the conditions nowadays, the best drive with all kinds of surface vessels is achieved with helical screw and there are four ways to drive it. First, directly on the shaft of a primary engine; second, with a help of gear transmission; third, by way of hydraulic transformer; fourth, by way of electricall power transmitter. Each of these methods has its good and its bad sides. As for the electrical drive, it is economic and can achieve results that no other drive can. Electrical drive has complex influence on ship's motion.".

From the military standpoint, the electric drive superiority might prove itself if one considers the precision, simplicity and speed of steering and maneuvering. Everything can be achieved by pressing one of the buttons. By changing the rotation direction of the electromotor a ship at full speed can be halted to a stop before it makes the distance equal to its own length. The ship will be able to maneuver very quickly and in such a way that was never dreamt of in the past.

When talking about battleships, Tesla remarked: "There is one more, stronger reason to adopt electrical drive. It is based on the recognition that in not so faraway future the means and methods of conducting war will be changed by applying the electrical force in a new way."

Contemporary battleship development

By the end of 1980s, contemporary electric drives with power higher than 20 MW started to be studied for military purposes, in order to create a ship more adaptable, of modular construction, capable to execute various tasks, and with better navigation and functional abilities than the existing ships.

Some ten years ago in the USA a 10 MW synchronous motor with permanent magnets [3] for ship drive started to be developed. In this way several problems are being solved: starting the motor is simple, speed regulation range is wide, reversing the propeller takes less time, ship's maneuverability is good and propeller efficiency is high. The electromotor being AC weighs less and costs less than a corresponding DC motor.

1) Institute of Technical Sciences SASA, Knez Mihailova 35, 11000 Beograd
2) Military Academy, Logistics Department

Table 1. Basic technical data on the integrated supply system

Integrated supply system	
Gas turbine generator	1 x 21 MW
GRT	4160 V
Modern asynchronous electromotor	1 x 19 MW, 0 – 150 min^{-1}
Cycloconverter	1 x 19 MW
Harmonic filter	

The US Navy is building 32 destroyers, class 21 (DD21). These next generation destroyers will be multipurpose, focused on strikes against coast targets. These destroyers will be the first class of ships designed and built in the 21st century and will develop according to the integrated architecture of electric power supply.

Integrated supply systems [4] are specially designed to be applied on battleships. It means that the electric drive complex with a 21 MW gas turbine generator supplies the main switchboard with 4160 V. The electric drive consists of a modern asynchronous 19 MW electromotor rotating in both directions from 0 to 150 rpm. A 19 MW cycloconverter and a harmonic filter, to repair the network voltage wave form, are being designed. This full scale development enables

- a great leap forward in technology
- application of new solutions
- easier design of a ship.

The All Electric Ship concept was developed, checked and tested in the merchant navy. The concept is based on a single electric power source which supplies the ship drive and all other devices including weapon systems. Good maneuvering properties are essential for battleships because of the nature of their tasks: navigation in shallow waters and maneuvering during landing and takeoff of aircraft on their landing decks.

The advantages of electric drive would be: lower price [04], lower noise level and simpler maintenance. The electric drive will create new possibilities for the ship design architecture, decrease in manpower, lengthening of ship's life, increase of security as wells as increase of electric power for new types of weapons. The main advantages are: increased battle operation abilities and better accommodation for the crew.

Some types of contemporary battleships

Some examples of various types of battleships with basic and electric drive specifications are given here [5]. The basic technical data and drive complexes of some battleships are shown in Table 2.

Amphibian landing craft US type LHD-8

This type of ship is 257 m long, equipped with two "POD" propulsion units with 3.7 MW asynchronous electromotors. The continuous speed regulation in both directions is done in the range 0-160 rpm for the full power range and in the range 0-130 rpm for one half of drive units. The supply and fixed pitch propeller speed regulation is done through converter transformers and water cooled 3000 MV cycloconverters.

Helicopter landing platform

The length of the helicopter platform is 199.5 m and the maximum speed is 18.8 knots. It has got 6 landing points and can carry 16 helicopters. The drive complex consists of two gas turbine generators. The generators supply 6.6 kV to the distribution board divided in two, and from the board ship's consumers are being supplied through two transformers. There are two harmonic filters in the network: they decrease harmonic deformity of the network voltage. The vessel is equipped with two "POD" propulsion units, 7 MW at 156 rpm each. The rotation of the "POD" unit is n x 360° while maneuvering (up to 10 knots) and it is limited to ±35° at higher speeds. This vessel is equipped with a modern communication network and a modern power regulation system.

Floating landing platform

The floating landing platform is 176 m long, its drive complex has two diesel generators, 6250 kW at 720 rpm each. There are two auxiliary diesel generators, 1560 kW at 720 rpm each. The diesel generators supply vessel's consumers with 3x6.6 kV through the distribution board. The vessel is equipped with two "POD" propulsion units with 6 MW asynchronous electromotors. The continuous speed re-

Table 2. Basic technical data for some battleships

	Amphibian landing craft	Helicopter landing platform	Floating landing platform	Antiaircraft destroyer type 45	Coast guard boat
Ship's specifications					
Length	257 m	199.5 m	176 m	152.4 m	128 m
Breadth	32.2 m	32 m	32 m	21.2 m	25 m
Draft	8.1 m		6.6 m	5.3 m	9.8 m
Displacement	40532 tons	22000 tons	19500 tons	7350 tons	16700 tons
Crew	1077	160	325	190	75
Drive complex					
Primary drive			2x6.25 MW 720 rpm	2x21 MW	4x720 kW
Auxiliary drive			2x1.56 MW 720 rpm	2x2 MW	2x700 kW
Electromotor	2x3.7 MW 0-130/160 rpm	7 MW 156 rpm	2x6 MW 0-150/180 rpm	2x20 MW	
GRT		6.6 kV	3x6.6 kV	2x4160 V	2x6.6 kV
Cyclo converter	2x3000 MV	2x12 pulses	2x12 pulses	2x20 MW	4x12 pulses
Harmonic filters	2 pcs		2 pcs		
Transformers			4 converter types	2 converter types	12 converter types and 2x3 MVA

gulation in both directions is carried out in the range 0-180 rpm for the full range of power and in the range 0-150 rpm with one diesel generator. The supply and fixed propeller speed regulation is carried out through 4 converter transformers and two 12-pulse cycloconverters.

Figure 2. Antiaircraft destroyer type 45

Antiaircraft destroyer type 45

The antiaircraft destroyer type 45 (Fig.2) is 152.4 m long, its drive complex consists of two 21 MW gas turbine generators and two 2 MW auxiliary diesel generators. The drive generators supply ship's consumers with 4160 V through the distribution board and two transformers. The vessel is equipped with two "POD" propulsion units with 20 MW asynchronous electromotors. The supply and fixed propeller speed regulation is carried out through 2 converters with pulse width modulation, 20 MW each. This vessel has got a modern power management system. In Australia [6] they consider various types of drive for this type of destroyers.

US coast guard boat

This boat is 128 m long and has got a drive installation consisting of four diesel generators, 7200 kW at 514 rpm each. It has got two 700 kW auxiliary diesel generators installed as well. The diesel generators supply boat's consumers with 6.6 kV voltage through the distribution board divided in two and two 3 MVA transformers. The boat is equipped with two "POD" propulsion units with 11.2 MW double coil asynchronous electromotors 11.2 MW each. The continuous speed regulation in both directions is carried out in the range 0-160 rpm for the full range of power and in the range 0-130 rpm with two drive units. The supply and fixed propeller speed regulation is carried out through 12 converter transformers and four 12-pulse cycloconverters. This boat has got a power management system and a dynamic positioning system as well as the 225 kW winch drive and the 55 kW steering drive.

Ship electric drive system

The ship bus bar is supplied by the gas turbine units (Fig.3). The auxiliary power supply is provided by diesel electric units of significantly less power than the gas turbine units. The high nominal voltage bus bars supply the ship "POD" propulsion drive units with most of the power and the bow and the stern thrusters are supplied with somewhat less power. Disturbances in the ship network created by the power converters demanded the use of rotating converters with older drives and filters to eliminate higher harmonics with modern solutions. Ship's general consumers are supplied with lower voltage through transformers which additionally diminish the passage of higher harmonics.

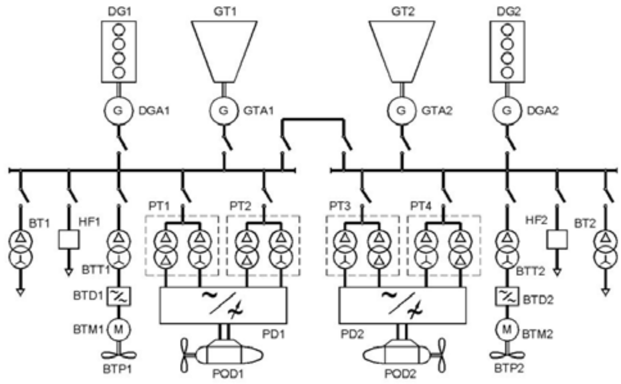

Figure 3. Scheme of supply of the ship network and main consumers

The "POD" propulsion units are supplied through voltage harmonizing transformers and 15 pulse cycloconverters in order to obtain a high quality variable frequency output voltage. The "POD" propulsion unit's synchronous or asynchronous motors have continually variable speeds both ways. The bow and stern propellers are supplied through corresponding transformers and converters. The speed of the bow and stern propellers, (their power being lower), is regulated by inverters which cost less.

The electrical power for the drive and for the ship systems comes from the joint high voltage distribution board, 4260 V or 6600 V. The distribution board is divided in two sections placed in different rooms and electrically connected by a cable with switches on both ends. The usual operation mode is when both switches are turned on. Each section of the distribution board is supplied by brushless synchronous generators driven by diesel engines. The generators are of high voltage and high power and they are designed so that they can operate with the power factor of 0.7 and with the permanent 5% overload. The generators have got two self lubricating bearings and a closed air/water cooling system. On the top of their stators they have got a heat exchanger. The permanent magnet generators supply a self excitation coil through an automatic voltage regulator. There is an interconnected choke installed to enable parallel operation. The electronic control distributes the load equally among the generators in parallel operation.

The 6600 V distribution board supplies the drive motors as well as a 1650 kW bow thruster, two transformers for ship's general consumption and a 500 kW compressor.

Drive engines

The chemical energy turns into mechanical work in the drive engines (diesel motors and gas turbines). In both cases the electric energy is being generated in the generators driven by the drive engines, which means that the mechanical energy is being turned into electric energy.

Some battleships have got very high power drive engines, the units of several MWs and even several tens of MWs. European manufacturers mainly use diesel motors because they are more economical and ergonomically acceptable, but American manufacturers use more powerful gas turbines. Both types of drive engines can be of ten found on a battleship. In that case one or both gas turbines are used for normal cruising and one or more diesel engines are used for slow cruising and docking.

The increasing number of applications of gas turbines was preceded by intensive development [7]. It has been three years since Rolls-Royce started marine gas turbine tests which will be terminated in 2004. The tests are being done on a 60 MW test bench in Bristol, Great Britain. The unit tested is more powerful than the well-known General Electric type LM 2500+, 36 MW nominal power at ambient temperature 26°C, or 30 MW at 32°C. The first fuel consumption test result is 207 g/kWh which is similar to the consumption of high speed diesel engines. The speed of the output shaft is 33000 rpm and the required alternator speed of 3000 rpm or 3600 rpm is obtained through a mechanic reduction gear. At the end of the exhaust system there are no visible exhaust gases. The gas turbine can operate 24000 hours without general maintenance repairs. Its weight is 22 t and its dimensions are 8.9x3.8x4 m. The Rolls-Royce firm claims that it is ideal for the drive of aircraft carriers, destroyers, frigates as well as for commercial ships.

Figure 4. The gas turbine type A 17 MW GT35 ready to be mounted

On the other hand European manufacturers prefer diesel engines. In the competition race the fuel consumption of diesel engines was reduced to 190 g/kWh and the life of high speed diesel engines was increased to almost 48000 hours.

Ship distribution system

There are two main high voltage distribution boards on board. Each main distribution board consists of two sections: a section for sensitive consumers and a section for insensitive consumers. Two sections can be connected through a switch which in the off-position while operating in the normal regime. The bus bars in the sensitive section are supplied through two rotating transformers (a set of synchronous motor/synchronous generator), 700 kW, 6600V/450V, 60Hz. The bus bars in the section for insensitive consumers are supplied through two dry distribution transformers of 2500 kVA each and of 6600V/450V. The primary coils of the transformers are star-connected and neutral points are connected. The secondary coils are delta-connected.

When supply comes from shore, the main distribution board gets 6600 V through the ship transformers. The transformer neutral point is connected to the ship ground through high resistance if the mechanically connected auxiliary bus bars are turned off. Two input connections forming the supply from shore are connected to the insensitive section of the distribution board.

The ship auxiliary distribution board is normally supplied through the sensitive bus bars and the bus bar connection. There is an auxiliary three phase generator, 2200 kW, 450 V, power factor 0.8, 60 Hz, meant for emergency supply. While at sea, the auxiliary diesel electric generator operates as a harbor generator and supplies both sensitive and insensitive bus bars. The auxiliary distribution board is connected by cable to the insensitive section of the main distribution board. This connection is turned on while switching from shore supply to ship's supply without switches.

Converters (Cycloconverters)

A cycloconverter is an AC-AC converter in which the output voltage wave form is produced from segments of input AC voltage waves [9, 10]. The cycloconverters can supply the stator with lasting current greater than the nominal one when necessary. The microprocessor control based on a modern regulation law (vector control) provides a high dynamic response in connection with an AC motor.

The cycloconverter circuits consist of 3 phase 6 pulse converters which supply two electromotor coils shifted for 30°, as shown in Fig. 3. Each motor phase is supplied by three phases of an anti parallel thyristor bridge. The thyristors are placed on the coolers cooled by water in a closed system. There are four completely independent cycloconverter groups with heat exchangers for two drive electromotors. The closed cooling system (deionized water) is equipped with a tank, manual pump and necessary valves to enable cycloconverter module replacement during operation.

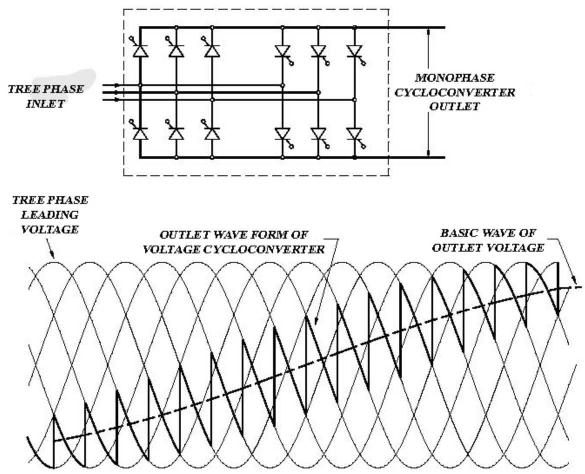

Figure 5. Three phase cycloconverter generating the lower frequency output voltage monophase basic wave

The cycloconverters are connected to 6600 V main distribution board through transformers (delta/delta and delta / star). The cycloconverter transformers are submerged in the transformer oil for the sake of more efficient cooling.

The cycloconverter shown in Fig.5 has got the following advantages:

- it eliminates 5, 7,… harmonic in the supply line and reduces total harmonic voltage distortion, which is necessary because of other ship's consumers;
- permits that one of the two distribution boards, placed in two engine rooms, can be turned off for the sake of maintenance and repair, while the ship drive operates at half;
- the motor voltage is optimal for any bus bar voltage;
- other modern controlling technics can be included in controlling the drive. It is important to notice that the

voltage harmonic distortion has its maximum while the shaft rotates slowly, at speeds close to 0 rpm and the motor is fully loaded.

The intensive development of new kinds of converting [11] and regulating circuits will lead to building more ships with electric drive.

Podid drives "POD"

The system of azimuth thrusters with electric drive was developed to improve ship's maneuvering ability. The electric motor drives one or two propellers directly. Their basic property is continual speed control in both directions from zero to the maximum speed. Besides, it is possible to rotate the whole "POD" round its vertical axis and get superb maneuvering abilities.

These compact drive units have been available on the market for some years, and are known as "Podid drives" [12] or short "POD". Further advantages of these drives are: flexibility of the diesel electric concept, continual regulation of propeller speed, easy way to reverse the propeller.

Even a better hydrodynamic property is obtained by positioning the propeller at the angle of 3 degrees. If one compares the "POD" drives with the conventional two-shaft drive, more hydrodynamic advantages will emerge: elimination of rudder and propeller support. Today there are four "POD" manufacturers on the market and their product are known as: Azipod, Mermaid, SSP and Dolphin.

The Azipod (azimuth podid drive)

The Kvaerner Masa Yards and ABB Industrie developed the Azipod which is in the market since 1990. In the meantime the range was increased up to 25 MW. The Azipod was first installed on the supply ship "Seili" of 1.5 MW. The conversion was done in 1991. Today the power installed ranges from 560 kW to 19.5 MW on different types of ships: inland water ships, icebreakers, luxury passenger cruisers. The new ship "Europa" will be equipped with two Azipods of 6.65 MW each.

The Mermaid

In 1994 the KeMeWa (Rolls Royce now) and the Alstom presented their version of "POD" in the range from 5 to 25 MW. The versions from 8 to 12 MW were installed on various passenger ships. Three 7 MW "PODs" were installed on a platform lifting ship. 19.5 MW "PODs" were installed on line passenger ships of Millenium class, built for Chantiers d' Atlantic, and on battleships.

SSP (Schottel-Siemens Propulsor)

The companies Schottel and Siemens are partners in the consortium SSP which manufactures azimuth thrusters. The development started in 1996. A wide range of conventional azimuth drives from 5 to 30 MW was developed. The first 5 MW SSP azimuth drives were made for a chemical tanker and 10 MW additional drives for a line ship.

The Dolphin

The companies Lips and STN Atlas presented their concept in 1998 but they have not sold anything yet. They produce azimuth drives from 3 to 19 MW.

Drive motors

All kinds of rotating machine were used to convert electrical energy into mechanical energy: DC, synchronous and asynchronous electromotors [14].

Heavier and more expensive DC machines have got a problem with commutation limits so that high power machines of this kind cannot be made. They cannot compete with AC machines for drives of largest ships, specially battleships.

The asynchronous motors were used for electric drives long time ago. The advantages of asynchronous motors are lower cost, simple design, and long life. The efficiency factor for a power higher than 1 MW is 0.96 while the gap between the stator and the rotor is the limiting factor for ship drive applications. A constant speed regime does not expose real advantages of these motors. The true advantages can be seen in a variable speed regime. There is no need to reduce gear to low speed.

Synchronous motors are still used for ship drive. In a constant speed and variable load regime the efficiency factor is up to 97%, which makes them suitable for ship drive. High power motors of this kind are manufactured, even higher than asynchronous motors, and with excitation without brushes their maintenance is simple and their life long. Their disadvantages are loss of synchronization when the supply is cut and higher price. 11 MW drive motor tests were done on icebreakers. The test study shows that synchronous motors are the best choice while asynchronous motors are more suitable for ocean-going ships because of their lower price.

Figure 6. ABB drive units

Two fixed propellers are driven to full reverse by varying speed of synchronous motors. Each drive electromotor is a 10-pole machine with double coil and with 11.2 MW output power at 10.83 Hz and 130 rpm. The motor is capable of giving 11.2 MW output power up to 160 rpm by reducing the magnetic field. The motor is designed in such a way that it provides maximum 175% of the nominal torque during 30 s. The two stator coils are phase-shifted for 30° and star-connected. Each coil is made for a nominal voltage of 2320 V and is supplied from a cycloconverter by 6 pulse voltage of variable amplitude and variable frequency. Such machine configuration provides the necessary drive reliability because one coil supplied by one cycloconverter can still drive the propeller with reduced power. Assuming that the propeller mechanical characteristic (torque/speed) is a quadratic function, one coil in operation can give 50% of the thrust and about 70% of the nominal ship speed.

Each electromotor has got a closed cooling system. The excitation coil is supplied through the thyristor converter and the slide rings. There is a spare set of slide rings and brushes.

In comparison with other electromotors, specially asynchronous motors, the synchronous motor advantages are:

- power factor value is 1 in the whole range of speed,
- lower shaft vibration torque because of higher rektansi of the coil, and
- larger gap is possible without reduction of high magnetizing current.

One synchronous motor (with two coils shifted for 30° per shaft) has got additional advantages:

- higher ship security because of two coils,
- lower level of vibrations and noise, and
- level of vibrations and noise is even lower because of the cycloconverter and a larger number of its cyclic variations and because two coils are installed.

Advantages of electrically driven ships

Compared to other types of power transmission from the drive machine to the propeller, electric drive has got several advantages [06, 15-17]:

1. Continual AC electromotor speed regulation. It is well known that the synchronous motor speed does not change with the change of load, and that the asynchronous motor speed varies only a few percent with the variable load from zero to a full load. Changing primary network frequency (by a cycloconverter or an inverter) enables continuous speed regulation in the whole range. It means that the ratio of voltage and frequency must be constant in the whole speed range so that the magnetic circuit should not become saturated. The second rule is that the magnetic flux should remain nominal.

2. Excellent ship maneuverability. By independent continuous speed regulation of each propeller it is possible to achieve any speed of propellers in opposite directions and improve maneuvering abilities of the ship.

3. Quick reversing of the propeller and backing at the same power as navigating ahead. The electric drive allows quick reversing of one or both propellers which shortens the holt distance and improves maneuverability. Besides, the electric drive enables backing at full power.

4. Elimination of the reversing device. Propeller reversing is contactless and it can be done many times in the course of voyage without additional wear or damage to the rotating parts.

5. Possibility of drive machines parallel operation. If there are several drive units (diesel electric power units) installed, it is possible to activate one or more power units, depending on the navigation conditions and required operating regime, and in that way to save fuel and operating hours of deactivated power units. Besides, if one of the power units breaks down the other power units will drive the ship at lower speed.

6. Possibility to switch off some of the drive units at low speed of navigation. When continuous low speed of navigation is required it possible for a ship to operate with only one power unit.

7. Possibility to set the optimum propeller speed. The electric drive permits setting and maintaining optimum propeller speed, depending on the navigation conditions and the ship cargo situation. It means that the drive machine load curve follows closely the propeller curve up to the nominal point and after that the propeller speed regulating is done with constant power.

8. Installing high-speed drive engines with high efficiency factor. Electric generators are high-speed machines (mainly 1500 rpm in Europe and 1800 rpm in USA), so high-speed diesel engines are installed to drive them because they weigh less and cost less. Besides, the whole diesel electric unit can be replaced when it breaks down.

9. Placing drive machines on the most convenient location. The drive units can be installed in the most convenient place on the ship and at any angle in relation to the ship axis.

10. Drive machine generator regime. The drive diesel engines operate in the generator regime which gives them better exploiting characteristics and longer life.

11. Supplying ship network by drive generators. The ship bus bars supply the ship network and make auxiliary diesel units unnecessary.

Other modern drives

The power control system controls generating and distribution of electric energy automatically. It integrates the steering system, the alarm system and supervision systems for drive machines, electric equipment, cargo and ballast.

The propeller speed or the ship propulsion power can be controlled from the following control consoles:

- the main ship control console,
- emergency control console,
- command station, and
- cycloconverter console.

The emergency control console and the cycloconverter console affect the drive controller directly. All other control consoles act through the processor at the emergency control console.

Although it is complex, the dynamic positioning process becomes easily attainable if one considers the development of electronic navigation devices and the possibilities offered by azipods and bow and stern thrusters driven and regulated by electric current.

The future battleships will possess very powerful devices and weapons. Besides, they will have to be more reliable and to be able to operate without errors and breakdowns. The application of the integrated power system will give the advantage of more efficient use of generator power.

Because of brief and extremely heavy loads, the efforts are made to store electric energy [18] which would be released in short intervals. A strong impulse of energy should be able to launch a weapon or set it into motion. As far as overloading is concerned, a diesel electric unit is more suitable than a gas turbine generator. Nowadays a brief and strong energy impulse can be obtained from various kinds of accumulator batteries, energy cells, mechanical flywheels or condenser batteries.

An electromagnetic catapult (Table 3) is being designed in order to reduce the length of the takeoff runway on aircraft carriers. The required characteristics of the catapult are: runway length 96 m, aircraft takeoff speed 77 m/s (150 knots), minimal required energy of the catapult 80 MJ, takeoff period 2.49 s, life 30 years.

Table 3. Basic technical data for the electromagnetic catapult

Electromagnetic catapult	
Takeoff speed	77 m/s 150 knots
Runway length	96 m
Takeoff period	2.49 s
Catapult minimal energy	80 MJ
Life	30 years

The electric drive easily supplies other ship powerful consumers: anchor and mooring winches, cranes, supply elevators.

Activating bow and stern thrusters, which are the most powerful consumers next to the main drive, can damage sensitive consumers connected to the ship network. This problem is solved by a gradual start of electromotors with the help of inverters.

Conclusion

Compared to other types of power transmission from the drive machine to the propeller, the electric drive has got several advantages:

- continual speed regulation of each propeller independently,
- excellent maneuvering properties of the ship,
- quick reversing of the propeller and backing at full power,
- elimination of the reversing device,
- possibility of parallel operation of several drive machines,
- possibility to switch off some drive machines at ship low speed (reduces fuel consumption),
- possibility to set the optimum propeller speed,
- use of high speed drive machines with high efficiency factor,
- installing of drive machines in the most convenient place on the ship,
- the generator operating regime of the drive machine, and
- supplying the ship network by the drive generators.

A conclusion can be made that electric drives on battleships have got significant advantages when compared to other types of drive, because the electric energy is used to drive weapons and other consumers on board. For smaller river ships electric drive is still too expensive except in special cases like floating crane.

References

[1] FREDZON,I.R. *Sudovbie elektromehanizmbi.* Gosudarsvenoe soioznoe izdetelbstvo sudostroitelbnoi promibišlennosti. Leningrad, 1958, p.5.

[2] TESLA NIKOLA. *Električni pogon ratnih brodova.* Članci, Aleksandar Marinčić, Zavod za udžbenike i nastavna sredstva, Beograd, 1995, pp. 432 - 441.

[3] ... US develops permanent magnet propulsion, The Motor Ship, August 1995, p.54.

[4] FACINELLI,W., MUGGERIDGE,D. Integrated System Analysis and Design of Podded Ship Propulsors, Marine Technology, July 1998, vol.35, no.3, pp.151-174.

[5] Prospektni materijal firme Alstom, Power conversion, videti i na http://www.powerconv.alstom.com

[6] LLOYD,C., SIMPSON,R., READ,G. The Type 45 Destroyer – powering to success, Proceedings of AES 2003, Edinburgh, 2003, pp.198-210.

[7] NEWMAN,R.J. *For the Navy, an engine of change.* U.S. News, 12.20.1999.

[8] ... Gas Turbine, From air to sea. *Marine Engineers Rewiev*, Febryary, 2003, pp.16 –18.

[9] RASHID,M.H. *Power Electronics Circuits.* Device and Applications, 1988.

[10] APRIANEN,M. *Naval Architecture of Electric Ships – Past, Present and Future*. SNAME Transactions, 1993, vol.101, pp.583-607.

[11] BUCKNALL,R.W.G., CIARAMELLA,K.M. *Potential use of matrix converters in marine propulsion applications.* Proceedings of AES 2003, Edinburgh, 2003, pp.133-143.

[12] NIINI,M. *The Need for Enhanced Manoeuvrability.* Proceedings Seatrade Cense Shipping Conference, Miami, 1995, Part III, pp.1-8.

[13] ... Annual Report 2000, Germanisher Lloyd, Ship Technology, 2000, pp.42-45.

[14] ... SSPs generate interest, The Motor Ship, May 2001, p. 25.

[15] ... Maneuvering with Podded Propulsors: Pluses and Minuses, Marin Report, October 1998, no.64, p.9, Netherland.

[16] DOYLE,T.J., STEVENS,H.O., Navy electric drive, http://peas.crane.navy.mil/IPS/intro/part1/index.html

[17] ALBERTS,P., KONING,J. "Pods in Service" initiative provides invaluable data. *Marin Report*, December 2001, no.75, pp.12 -13.

[18] DELISLE,D., DESAI,B., ROBEY,H. *Energy Storage for U.S. Navy Integrated Power System Applications*. Proceedings of AES 2003, Edinburgh, 2003, pp.340-352.

Received: 30.6.2004

Električni pogon savremenih ratnih brodova

U radu je prikazana transmisija električne energije na ratnim brodovima u svetlu najnovijih tehnoloških dostignuća. Takođe se razmatra i primena koncepta AES (All Electric Ship) na ratnim brodovima. Prikazani su moderni ratni brodovi na električni pogon, detaljno opisani i sistemi električnog pogona od proizvodnje električne energije do pogona brodskih propelera, a date su i prednosti električnog pogona brodskih propelera.

Ključne reči: **ratni brod, električni pogon, pogon POD, ciklokonvertor, invertor.**

Transmission électrique des navires de guerre modernes

La transmission de l'énergie électrique sur les navires de guerre est présentée du point de vue du dévelopement technologique le plus récent. L'application de la conception AES (All Electric Ship) sur les navires de guerre est aussi donnée. Les navires de guerre modernes à transmission électrique précédent la présentation détaillée des systèmes de transmission électrique – de la production de l'énergie électrique yusqu' à la transmission aux hélices de navire. Quelquies avantages de la transmission électrique chez les hélices sont également donnés.

Mots-clés: **navire de guerre, transmission électrique, transmission POD, convertisseur rotatif inverseur.**