Study on technical solutions for shore power supply of motor yacht

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Abstract. The report presents an analysis of modern technical solutions for shore power supply of a specific class of passenger ships - luxury yachts for charter trips. The design data of a motor yacht in its different operating modes are considered, as well as the energy mix related to the fuel consumption at shore supply of the yacht during its stay at the port. The use of modern technical systems for shore supply includes the application of specific frequency converters, through which compatibility between the different voltage standards and the frequency for different shore power supply systems is realized. The costs of onshore power, compared to those of marine fuel, can be calculated from the current prices of onshore electricity and the energy produced from its own generators. The analysis of the basic design data of the motor yacht and the assessment of the energy costs on board, fuel economy and emission reductions will provide a clear answer to the advantages of the power supply from the shore of the vessel.

1. Introduction
Motor yachts are a specific class of passenger ships, which in recent years have played a growing role in the overall energy consumption of shipping. The reason for this is the high demand for yachts that have more tourist than transport function and have a large sailing distance. Modern luxury yachts reach lengths up to 90 m, tonnage up to 2500 GT, speed up to 20 kn and passengers and crew up to 50 people. These parameters place the yachts in the class of small passenger ships, but with increased requirements for the comfort of the environment. For this reason, it is necessary to use powerful propulsion systems in the range of 2-4 MW and machinery equipment with high energy consumption in the range of 0.5-1MW. Luxury yachts also have significant specifics in terms of sailing regimes.

They are characterized by a much longer stay in ports than other types of ships. In some cases, this period can vary from days to several weeks. For this reason, in order to reduce fuel consumption and reduce greenhouse gas emissions, a shore power supply is used for all equipment and energy consumers on board. The use of shore power is related to the following problem - yachts can visit ports that have different standards for the level and frequency of the supply voltage (50 or 60 Hz). This predetermines the need for analysis of the specifics, technical means and modes of electricity consumption of superyachts in shore supply mode. The problem is relevant, because different technical solutions for shore electric power supply have different advantages and disadvantages. The report presents a study of some types of technical solutions for shore supply of superyachts.
2. Study on the technical solutions for providing shore electric power supply for motor yachts

The basic standards for the on-board power supply system of yachts are: European – 400/230V 50Hz; USA – 460/265V, 240/120V 60Hz; China 380/22V 50Hz; Japan 220/110V 60Hz. This shows the existence of significant differences in voltage levels and frequencies for different countries. The safe connection of a yacht to the shore supply requires the application of special technical equipment.

2.1. Technical solutions for shore electric power supply with frequency conversion

Classical means for converting voltage and frequency include the use of specialized motor-generator groups (figure 1). In this case, the frequency conversion is performed by changing the speed of the electric motor. This can be done with specially designed electric motors or with the use of standard frequency regulators, allowing achievement of rotation above the synchronous speed. A significant disadvantage of the method is the weak unification - it is possible one-way conversion of voltage and frequency from one standard to another, but not in the opposite direction. The large mass and size parameters of the equipment do not allow to be installed on board a ship. Yachts may use this type of shore supply only in ports that are specially equipped with such facilities. Usually, this type of equipment is designed as mobile in standardized containers and can be moved from one port to another, but this involves significant additional economic costs, which significantly reduces the effect of their use. In practice, they are used where it is planned to permanently dock yachts which are produced according to different voltage standards from the shore network. Due to the double conversion of electricity, which is accompanied by additional power losses, the solution is less efficient than modern solutions without the use of electrical machines [1, 2].

Another way to convert voltage and frequency for shore supply is associated with the use of specialized galvanically separated inverters (figure 2). For this purpose, it is necessary to use a isolating transformer with sufficient power to transfer the required electricity. The advantage of the method is that due to the absence of electrical machines, greater energy efficiency and lower additional losses can be achieved. The technical means allows the two-way conversion of voltage and frequency - a yacht manufactured according to European standards to be powered by an American network or vice versa [3]. This type of equipment has smaller dimensions and can be produced both as additional equipment to the port infrastructure and to be manufactured for installation on board the yacht. Due to its great unification, this type of solution allows a yacht manufactured to a certain standard to be powered by all types of port infrastructure around the world.

![Figure 1. Voltage-frequency conversion system with M-G group for shore power supply](image-url)
2.2. Technical solutions for shore electric power supply without frequency conversion

This type of solution involves the use of a specialized multi-stage isolation transformer (figure 3). The initial connection of the windings is carried out with current-limiting resistors, as the stages are determined manually or with the use of a programmable logic controller. This solution is widespread for yachts whose electrical equipment is not sensitive to changes in feed frequency. The solution is applicable to older generations of yachts, where the main lighting is with incandescent light sources, and the electrical equipment is designed to operate at different frequencies. With the introduction of power electronics and frequency converters on board yachts, this solution is gaining popularity again.

This is possible if all electric drives on the yacht are equipped with inverters that can operate at different frequencies and all lighting systems have electronic drivers for LEDs or gas discharge sources operating on both basic standards.

![Figure 3. Voltage conversion with multi-stage transformer](image3)
3. Analysis of the power consumption of a motor yacht in shore power supply mode

3.1. Object of the study
The object of the study is a luxury yacht for charter trips with the following parameters: Length – \( L_{\text{LW}} = 70.5 \) [m], Gross Tonnage – \( \text{GT}=1560 \) [t], Max. speed – \( V_{\text{MAX}} = 17 \) [kn], Cruise speed – \( V_{\text{CR}} = 15 \) [kn], Crew = 39. A view of this class of yachts is shown in figure 4.

![Figure 4. Superyacht GT 1560t, L=70.5m, Crew 39](image)

3.2. Energy parameters of superyacht GT1560
The yacht is powered by two diesel engines 2x1825 kW and three diesel-electric generators 3x200 kW. The electrical consumers are divided into four main groups: Group 1 “Machinery Equipment” (\( P_{\text{INSTALLED}} = 250.2 \) kW), Group 2 “Boiler/Fan/AC Unit and Water Supply” (\( P_{\text{INSTALLED}} = 412.3 \) kW), Group 3 “Winches” (\( P_{\text{INSTALLED}} = 82.6 \) kW) and Group 4 “Other Equipment” (\( P_{\text{INSTALLED}} = 150.4 \) kW). The design data on energy consumption for all groups depending on the operating modes are shown in table 1. The data show significant electricity consumption in shore electric power supply mode - 332.63 kW or 37% of the total installed power. The shore supply of the studied yacht is carried out through a shore supply system of type 2.2 (without frequency conversion) installed on board with a nominal power of 400 kVA. The switching of the transformer stages is automatic, performed by a programmable logic controller Simatic S7. The energy balance relative to the actually consumed electric power and energy is shown in figure 5. The shore power supply amounts to 26% of the total energy consumption [4, 5].

Table 1. Total Electricity Consumption

| №   | Consumer | \( P_{\text{INST}} \) [kW] | \( P_{\text{W}} \) [kW] | \( P_{\text{W}} \) [kW] | \( P_{\text{W}} \) [kW] |
|-----|----------|-----------------|----------------|----------------|----------------|
| 1   | Group №1 | 250.2           | 47.39          | 15.81          | 221.8          |
| 2   | Group №2 | 412.14          | 233.33         | 227.51         | 231            |
| 3   | Group №3 | 82.56           | 3.39           | 9.31           | 17.31          |
| 4   | Group №4 | 150.4           | 88.7           | 80             | 83.9           |
| Total|          | 895.3           | 372.8          | 332.63         | 554.01         |
4. Conclusion
The report discusses the advantages and disadvantages of using different types of shore power supplies for superyachts. An analysis of an on-board shore-type power supply system for the GT1560 superyacht is presented. The results show a significant share of energy consumption in shore supply mode - about 26% of total energy consumption. The use of onshore supply instead of generators on board the ship leads to an identical reduction in emissions. It should be noted that the onshore supply regime is not specified in the definitions for Energy Efficiency Operational Indicator (EEOI) and Energy Efficiency Design Index (EEDI), as in this case there is no transport work. That is resulting into quantitative value of indexes which become mathematical uncertainty. The report shows two significant issues requiring future research - improving port infrastructure to meet the needs of the growing number of superyachts and the problem of assessing their environmental impact in ports, which is not possible with the standard definition of EEE and EEDI.

5. References
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Figure 5. Energy balance and energy mix in shore power supply