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# Analysis of using and operating conditions of the naval power equipment according to the wave-induced ship load

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**Abstract.** This article analyzes the conditions of operation and exploitation of the ship's power equipment using the meteorological conditions and the type of ship. Based on the naval power systems and new shipbuilding technologies, we are looking for optimization and increased reliability of shipboard automation and navigation systems that are on board. The article analyzes and presents solutions about the complex problems that arise in the work of the engineer that is on board. It is demonstrated the importance of the quality indicators of the naval power system for improving the operating conditions of the existing plants and to modernize the ship by providing new equipment and computers whose optimal working is influenced by the quality of the electrical energy that is onboard. In this paper it is followed the ranking of the implemented control, monitoring and protection of the electrical energy system and the propulsion power of the systems, in which the physical and functional integrity is a vital design philosophy. This can be centralized or distributed by the computers. The study of the waves is done in order to estimate the induced demands in the structure of the ship and their influence on the equipments and the devices that are on-board. The analysis is performed using experimental and theoretical values as input data in the analysis with finite elements. For the estimation of structural strength of the ship and on-board equipments it is necessary to determine the extreme values of the wave-induced loads

## 1. Introduction

The ship is a conglomerate that includes elements in many areas and requires interdisciplinary research to address the issues of buoyancy, stability, unsustainability, maneuverability, road stability and marching qualities, with the aim of increasing the safety of electricity supply to consumers. increasing the energy efficiency in its production and distribution. In the design, construction and operation of ships, new principles are used which combine theoretical elements with experimental results. It seeks to find technical, economic and scientific solutions for carrying on board a new standard of profitability and quality.

The study of nautical qualities of the naval vessel requires the introduction of geometric features to verify physical phenomena that act on the body and onboard equipment[1]. Analysis of Naval Power Systems (N.P.S) and their optimization has been a permanent concern for engineers and researchers. The reliability of on-board automation and navigation systems depends to a large extent on the quality of the electricity that is delivered aboard the ship [2,3]. The ship's body is a complex and elastic system subjected to static and dynamic loads. It is considered to be a complex beam, variable section, free at the ends, elastic medium, in water[4]. All installations and equipment to be fitted on board a ship shall comply with naval registers. Each part of a seagoing ship, outer shell, rigid building and adjoining buildings must meet the requirements imposed by the marine environment and

meteorological conditions. Knowing the quality indicators of the naval power system is important both for improving on-board facilities and for upgrading the ship by providing new equipment and computing whose optimal operation is influenced by the onboard power quality. The indicators for assessing the quality of the electricity produced by the naval power system are: deviation of average tension; deviation of line voltage; coefficient of non-symmetry of voltage for nominal frequency, transient voltage deviation; the time of return of the voltage; peak voltage; voltage distortion factor; the individual distortion factor, the deviation factor; frequency mismatch, frequency unbalance coefficient, transient frequency deviation, frequency recovery time [5,6,7, 8]. The electricity supply to shipboard consumers must be in line with the energy quality standards imposed by international bodies [8]. Traceability of electricity quality indicators and the adoption of measures to keep them within acceptable limits can only be correlated with tracking disturbances introduced into the power grid. The system of quality indicators for electricity refers in particular to disturbances caused by the consumers' functioning: harmonics and interharmonics (non-sinusoidal regimes); rapid voltage fluctuations; slow voltage fluctuations (flicker effect); Harmonics and interharmonics, rapid and slow fluctuations in voltage, as well as unbalances, impair the quality of the energy given to consumers, and the proper functioning of their equipment is affected. Quality indices can be calculated, but it should be known that electricity is polluted with higher-order harmonics that damages the operation of navigation devices and electrical machinery on board the ship. Figures 1-6 have graphically represented variations in time of the quality indices calculated for one beam forward beam [9,10,11,12,13].

The maximum permissible limits of voltage deviation are  $\pm 10\%$  for permanent mode and  $\pm 20\%$  for 1.5 seconds or  $\pm 30\%$  for 5 seconds for short mode and for frequency  $\pm 5\%$  for permanent mode and  $\pm 10\%$  for 5 seconds for short mode.

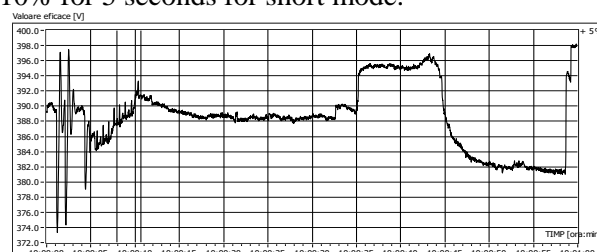


Fig.1. Deviation of average tension time[s]

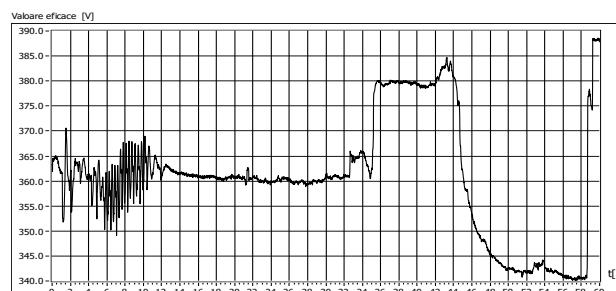


Fig.2. Deviation of line voltage time[s]

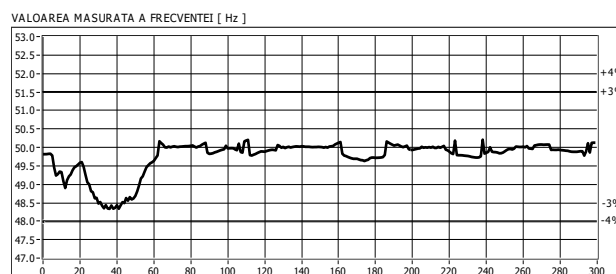


Fig. 3. Frequency deviation time[s]

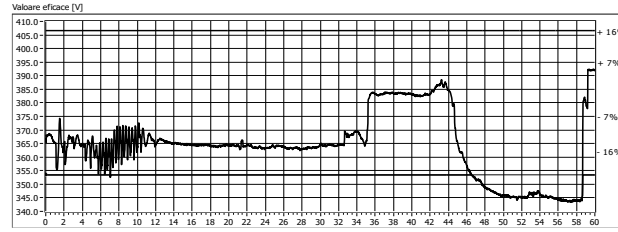


Fig.4. Transient voltage deviation time[s]

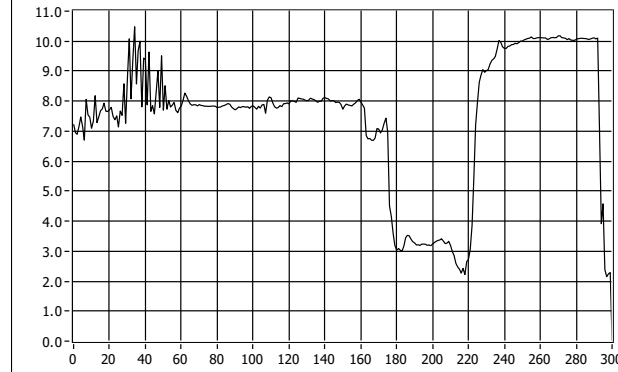


Fig. 5. The individual distortion factor time[s]

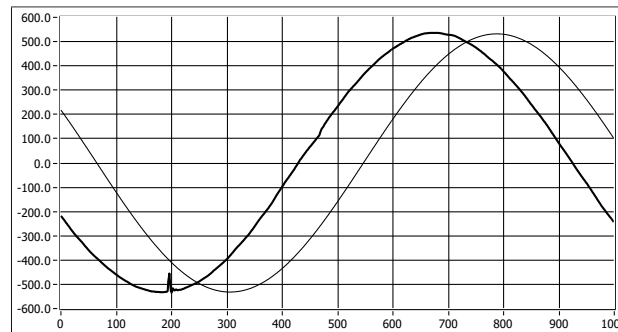


Fig.6. The deviation factor time[s]

## 2. Analysis of wave demands

Survey of waves is done to estimate the induced demands in the structure of the ship and in on-board facilities and equipment. The values obtained are used as input data in the analysis of cumulative effects on the ship. As a mathematical apparatus, we use the finite element method that allows the estimation of the response of a large structure. By analyzing the observed or measured data over a long period, the cumulative distribution probability is determined empirically. If experimental data is obtained over long periods of time, the probability of cumulative distribution can be approximated based on the asymptotic distribution probability theory. By simulating the behavior of the ship's structure over waves over long periods of time and by estimating the extreme values resulting from the simulation results, the statistical values of a long-term simulation are more accurate than those obtained by short-term measurements. These results are applied to a statistical model that allows extraction of probable extreme values. As models apply: Weibull model, Hermite model: Gumel model. Resistance calculations use values derived from the statistical distribution of waves. In the case of the linear response analysis, there are theoretical methods to determine the probability of short and long term distribution of stresses in the ship's body and in on-board installations and equipment, and in the case of non-linear static analysis the results are empirical [14,15]. Rayleigh's distribution describes the short-term distribution of wave-induced demands for a spectrum considered narrowband. For long-term distribution, the weighted sum of short-term values for different ship, vessel speed and route values shall be determined.

The research and results achieved are centralized in Table 1.  
Table1. Distribution probabilities for non-linear short-term response

Distribution function	Type of response	Ship type	Validation procedure
Weibull	Bending moment vertically	Container, tank, navy	Numerical simulation
Weibull	Moment of bending, moment of whipping	Cruise ships	Experimental Measurement
Weibull	Moment of confrontation	Container	Numerical simulation
exponential	Moment of whipping	Container	Numerical simulation
Gumel	Moment of confrontation	Nave de viteză	Numerical simulation
Rayleigh t	Water overboard	Cargo and tanks	Experimental Measurement
Weibull	Water overboard	Container	Experimental Measurement

The wave spectrum is very important in estimating wave characteristics; in other words, the discovery of a spectral density function from the experimental data is equivalent to the overall characterization of the sea surface. Data on collected waves led to some wave distribution laws, depending on spectral densities. The laws may have two to six parameters for a complete definition and represent the area from which experimental data has been obtained. Wave height values have a normal distribution function (Gauss), and peak wavelengths have a Rayleigh distribution function. The analysis of wave spectra is closely related to the movement of the masses of air in the adjacent area. The aim is to develop a base ship that coordinates the control of the hardware systems that are responsible for safe ship maneuverability, taking into account certain factors (wind, wave) as well as systems that control the position, transverse tilt, and speed, plus propulsion. In the Integrated Control System (CSCES) an essential component is the IBC (Integrated Bridge Control) control system. The IBC consists of workstation modules for the commander, the driver and the helmsman. These modules are used for: Technical data acquisition, analysis and operation; ship navigation safety, vessel and speed control, remote monitoring of the the Naval Power Plant(NPP) with all its related components, ship and navigational safety monitoring, monitoring of the main power plant parameters and unscrewing systems, maneuverability and reliability. stability[ 16,17].

### 3. Analysis of naval power systems and their optimization

The analysis of the naval power system starts from the production of electricity, continues with the consumers, and an analysis of changes in the structure of the system is made by reducing the electricity consumption. The implementation of measures to reduce electricity consumers brings savings in the operation of the ship and the drop in the prices of goods transported by water. Comparative Estimation of Electricity Consumption Using Classical and Dynamic Prediction Methods of the Loop Curve Provides Conclusions to Consumer Choice[18,19].

The essential feature of ship electrical installations is complexity. Today, a small ship would be unthinkable without an electrical installation. Each ship has to carry its own electricity source. On the ship there is an electricity distribution network, power consumers of the most diverse types, lighting installations, heating installations, household installations, signaling and automation installations of various mechanisms and devices, radiocommunication installations and other

installations special purpose electrical equipment (demagnetizing installation, cathodic protection installation, radioactive signaling facility, rolling stabilizer etc.) This complexity of ship electrical installations requires a large number of specialists to build and operate them. In shipbuilding and research and design institutes a specialization is possible based on plant types. On board the ship, where there is a small number of personnel, the electromechanical officer must be aware of all the problems connected with the proper operation of the electrical installation on board

The naval power system (N.P.S.) must ensure: independent and parallel operation of the generators; interconnection of block-sections of the main switchboard, disconnection and automatic connection of stand-by units, protection of generators, electric motors and other consumers from the occurrence of abnormal operating modes, automatic disconnection of non-essential consumers, operation of measuring and control devices in case of overload, short circuit, over and subfrequency and reverse power, etc. The ship's electrical installations must have a high robustness and increased operational safety due to the heavier climatic and technical conditions on board and the fact that during the race the ship becomes an isolated system that can not be helped in a crash case. These particular operating conditions must be taken into account in the construction of ship equipment, machinery and equipment [20,21,22]. These are: a) ambient temperature. In closed compartments with heavier ventilation conditions, temperatures above ambient temperatures (temperatures of  $+ 70^{\circ}\text{C}$  to  $+ 75^{\circ}\text{C}$ ) may be much higher. In the technical compartments, as a result of the maximum utilization of available space, a large amount of radiated heat of machinery and appliances is produced. The high ambient temperature has a negative effect on the technical characteristics of electric machines and appliances. Thus, the increase of the ambient temperature from  $+ 30^{\circ}\text{C}$  to  $+ 40^{\circ}\text{C}$  in an electric machine leads to the decrease of its power by about 10%. Practically increasing the ambient temperature leads to an increase in the dimensions of the gauge and the weight of the electrical equipment; b) Relative air humidity at sea and water is between 70% and 95%, reaching tropical values up to the saturation limit. Unlike relative humidity, absolute humidity is differentiated. Thus, under saturation conditions at  $-20^{\circ}\text{C}$ , one cubic meter of air contained 1 g of water. At tropics, during rain the humidity is 26 to 30 g of water per cubic meter of air. When the air has a high degree of saturation, only a few degrees of cooling is sufficient to produce excess water condensation. Thus condensation water is formed on the structural elements and on the ship's installations. The condensation water, in addition to the corrosion effect, leads to a decrease in the insulation resistance, the generation of contamination, or the occurrence of electrolysis. Condensation water can penetrate inside electrical equipment. For this reason, the insertion of cables into machines and appliances should be done, as far as possible, only on the underside of the protective casing; c) the salt content in the air. The aggressive effect of condensation water on ship installations is increased by the salt that condensate water takes from the air. The content of salt particles floating in the mid-wind wind (5-6 Beaufort - Scale for assessing wind and sea level) is about  $0.01\text{ mg} / \text{m}^3$ . Close to the coasts and strong winds (10 Beaufort) the salt content rises to about  $1\text{ mg} / \text{m}^3$ ; d) the oil content in the air. In the engine compartment, especially around diesel engines, there is a relatively high oil content in the air, so over diesel engines can reach  $3\text{-}20\text{ mg} / \text{m}^3$  of air. The penetration of oil and gas into electrical appliances and machines, in combination with coal or other conductive particles, produces mixtures that reduce the insulation resistance of coils or other current paths; e) contact with seawater. Electrical installations located on the open deck are exposed directly to seawater contact. This contact can occur by spraying, spraying, flooding or full water coverage over short periods of time. Contact with seawater particularly affects the operation of electrical installations. In addition to the corrosive effect, contact with seawater also produces mechanical stresses from the pressure exerted by the water column that floods the plants. Thus, a static pressure arises due to the height of the water column and a dynamic pressure due to the speed of the water passing over the installations. The force resulting from static and dynamic pressure introduces water through sealing gaskets, separation joints, etc. Since screw threads, however well executed, can not provide sufficient guarantees, it is recommended that the screw caps are fastened in such a way that they do not penetrate the inside of the box. In the case of cold-sea navigation, open deck installations may come into contact with ice; f) corrosion. Ship electrical installations must be characterized by increased corrosion resistance. Corrosion is particularly active in shipboard conditions due to the large amount of salt contained in sea water and air humidity. At the contact point of two different metals (contact that occurs in the assembly, assembly, protective coating, etc.) an electromotor voltage occurs. Lower-potential metal will serve as anode and potentially higher cathode. In shipbuilding, for economic reasons, steel is used, but special corrosion

measures must be taken in this case by protective coatings that may be metallic (zinc, cadmium, tin) or chemical (paints); g) operation in dynamic regimes. Most on-board electrical equipment intermittently operates with rest periods longer than operating ones. Intermittent operation is more disadvantageous if it continues, on the one hand, due to the acceleration of material aging, and on the other hand during the pause there are favorable conditions for condensation of water, maintaining the moisture state and therefore the corrosion effects are more active. To avoid the above mentioned effects, it is necessary to install electrical resistors inside the machines and appliances; h) Vibrations and shakes find a propelling and amplifying environment in the steel structure of the ship. The ship's electrical equipment must be so constructed as to withstand these stresses. Vibrations appearing on the ship may be general and local. General vibrations are due to the action of the waves and the propeller on the ship's body, and the local ones due to uncompensated inertial forces of some piston mechanisms or machines (diesel engines, compressors, pumps). The frequency and amplitude of the vibrations are very different and rather difficult to predetermined and localized. The electrical system must operate continuously at a throttle acceleration of up to  $30 \text{ m/s}^2$  and at frequencies of 40-80 strokes per minute; i) operation in dynamic regimes. Most on-board electrical equipment intermittently operates with rest periods longer than operating ones. Intermittent operation is more disadvantageous if it continues, on the one hand, due to the acceleration of material aging, and on the other hand during the pause there are favorable conditions for water condensation, maintaining the moisture state and therefore the corrosion effects are more active. To avoid the aforementioned effects, it is necessary to install electrical resistors inside the machines and appliances; j) operation in inclined positions. During march, a ship may be subjected to longitudinal and transverse slopes. This inclination can be short-lived (due to waves) or long-lasting (due to crash situations). All components of the electrical installation must be safe to operate and can be operated in any of the ship's tilting conditions. The rules for the classification and construction of sea-going vessels prescribe that the electrical equipment shall operate without failures in the event of a tilt (tilting the unstable ship from the straight edge of the ship to any position) for up to  $15^\circ$ . Hazardous electrical installations must operate at the same time, without failures, with a long transverse inclination up to  $22.5^\circ$  and a longitudinal inclination up to  $10^\circ$ . The effect of tilting and oscillations of the ship is the emergence of additional shear forces due to gyroscopic forces and components of gravitational force. To diminish this effect, all horizontally powered electric cars are mounted so that the shaft is parallel to the diametrical plane of the ship as the longitudinal plane inclinations are smaller than in the transverse plane. In order to ensure good service and safety conditions due to the ship's oscillations, main switchboards, control panels and signposts, electric cooking plates, etc., shall be placed as far as possible across the ship. When the ship is oscillating, the movable elements of the electric apparatus which move in the plane of the ship's oscillations may receive additional stresses that lead to undesired closing or opening of normally open or normally closed contacts.

#### **4. Rules for the execution of electrical installations on board commercial ships according to the ship's requests**

Of the meteorological phenomena with particularly intense manifestations and of interest in navigation, the storms are of interest. We have synthesized the synoptic data in the Black Sea resulting in the western part being more demanded by barric disturbances than the rest of the sea, due to the higher frequency of the cases of cyclogenesis and anticyclone. The necessary conditions for triggering storms are mainly created during the cold season of the year when over the warmer waters of the sea predominate depression barrier fields with unstable air stratification and with horizontal gradients of high wind velocity. The most intense storm in the Black Sea is the one from 1981 (maximum speed  $24 \text{ m/s}$ , average  $17.5 \text{ m/s}$ , 84 hours between 8 and 11 January). The longest storm recorded during this period is that of 1991, December 6-10 with an average wind speed of  $16.9 \text{ m/s}$  and a total duration of 102 hours. With the help of statistical storm analysis, the parameters of the dangerous waves for navigation can be determined: on the isobot of 8-10 m in the Constanta area, the height of the waves can reach 5.5-7.0 m in the big storms, at the same time as the sea level rise above 90 cm from the multiannual level, propagation velocity  $c \text{ [m/s]}$ , height (mean amplitude) in the wave field. The agitation of the sea is given through a 9-step scale that correlates with the 12-step international wind scale (Beaufort scale), the wave scale and the hula scale. The waves are characterized by height (amplitude)  $h \text{ [m]}$ , length  $L \text{ [m]}$ , period. The magnitude of the wave is an

element of particular interest and depends very much on the wind velocity  $V_w$  [m / s], the duration of the wind  $T_h$  [hours], the action distance of the sea fetch -  $D$  [km, M]. It has been found that wind waves are more numerous (> 80%) than hula waves (> 20%) and their diminishing or extinguishing occurs in situations of prolonged atmospheric calm or when the wind starts to beat in the opposite direction to their propagation. The increase or decrease of the wave height is achieved with some delay against the wind speed fluctuations. Increasing the height of the waves does not occur only in case of wind intensification; it occurs even at constant speeds but lasting and in the same direction. From an electrical point of view, the power control system monitors and controls the functionality of the power system globally, integrating it into a fully integrated and automated system power [23]. It is aimed at: the hierarchy of the implemented control, the monitoring and protection of the electric power system and the power of propulsion of the systems, in which the physical and functional integration is a vital design philosophy. They can be centralized or distributed by computers [24]. These will include power management functions (power management, stopping prevention methods, startup and reconfiguration of control sequences for electrical equipment). Due to the need for separate testing and clear accountability, there will be a need for quick response to the control, monitoring and protection of devices and components. Here are the quick control functions and security features implemented. These are related to the level of control of the system through an interface.

## 5. Conclusions

In order to estimate the structural strength of the ship, it is necessary to determine the extreme values of the induced stresses. Determination of forces created by waves is done using the statistical theory of extreme values, notions of hydrodynamics, probability theory, analysis of experimental data, and numerical analysis. In the structural analysis of vessel behavior during operation, the extreme value of the load created by the waves must be known. In practice, this value is known or approximated depending on the height of the wave. The interconnection point for all electrical equipment installed on board is the Central Control Point (C.C.P.). Starting with transient customers, generating large variations in load and ending with network disruptions from the effects of higher harmonics, all equipment starting with the generators interacts and interacts with each other. The optimum operation and control of the power system is the fundamental criterion for the safe operation of low-fuel electric equipment. Marine generating stations must provide mechanical and electrical power for propulsion and for many other purposes on the ship. They must serve all needs and needs (heating, cooling, transshipment, transfer, etc., which, under certain conditions, require more power than propulsion). Reliability is a requirement for safe and economic operation of the ship.

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