



Integrated Management System for Equipment and Power Supply Systems in the Navigation Compartment of a Seagoing Vessel using Artificial Intelligence

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Abstract. The paper presents the importance of the modern naval transport and the integration of artificial intelligence (AI) in navigation systems. The importance of navigation equipment to meet the requirements of energy efficiency, operational safety and sustainability is emphasized. The need for energy optimization, automation and cybersecurity is underlined. The quality of electrical energy and its impact on the operation of equipment is analyzed. Concepts related to harmonics, electromagnetic compatibility (ECM), on-board electrical distribution and the characteristics of navigation equipment are presented. The optimal operation of electronic and Information Technology (IT) equipment on board is closely related to the quality of electrical energy. The key concepts regarding voltage distortions and frequency fluctuations are analyzed. The sensitivity of navigation equipment to electrical disturbances and the need for intelligent energy management are studied. The role of AI in monitoring navigation equipment is highlighted, including the description of the IT architecture, data flows and automatic signal analysis processes.

Keywords. Power supply systems, Navigation management

1. Introduction

In the era of accelerated digitalization and automation, maritime transport is undergoing a profound transformation, marked by the integration of smart technologies in all areas of naval operation. Modern ships are equipped with complex navigation, communication, monitoring and control systems, which generate large volumes of data and require fast and secure decision-making processes. In this context, the integration of artificial intelligence (AI) in navigation equipment management systems represents not only a technological evolution, but a strategic necessity for increasing energy efficiency, reducing maintenance costs, preventing damage and ensuring a high level of cybersecurity [1], [2].

The paper aims to create an integrated management system for equipment and their signals for navigation systems on board ships, based on artificial intelligence, which allows: automatic collection of operating data; predictive performance analysis; anomaly detection; alarm management;



maintenance optimization, with a focus on cybersecurity and energy efficiency. The aim is to achieve the following objectives: analysis of existing navigation systems and of the electrical and electronic equipment on board ships from the perspective of energy quality and electromagnetic compatibility; modeling the energy consumption of the main navigation equipment (radar, Electronic Chart Display and Information System (ECDIS), Automatic Identification System (AIS)), in order to identify critical points and optimization possibilities; simulation of the acquisition and processing of data from navigation equipment using machine learning algorithms; development of a predictive model based on artificial intelligence to identify failures and prevent incidents in the operation of equipment; automatic classification of alerts generated by navigation systems and creation of an intelligent adaptive alarm system; development of an integrated maintenance strategy, combining preventive, corrective and conditional methods based on the analyzed signals; implementation of a software framework for managing and analyzing data from naval equipment in real time; integration of cybersecurity requirements into the system's operating model, in accordance with International Maritime Organization (IMO) regulations and international good practices; evaluation of the efficiency of the proposed system by comparison with classic solutions, using simulations and specific scenarios [3], [4].

2. Power quality and its indicators

Power quality problems occur when the voltage deviates from its nominal values or when the waveform is affected. [5], [6]. The shipboard electrical network is characterized by the presence of periodic but distorted voltage and current waveforms. These distortions can be described by means of Fourier analysis, which allows the representation of signals as a sum of harmonic components [7].

The evaluation of the harmonic distortion level is done by analyzing the individual voltage (U_n) and current (I_n) harmonics. The reference indicator used is the total distortion factor – THD (Total Harmonic Distortion), specific to non-sinusoidal periodic regimes. [8].

For electrical networks on board ships to meet modern requirements for optimization and efficiency, they must respect a number of essential functional principles: flexibility; accessibility; security; economic efficiency [9].

Technological advances in the field of energy supply, intelligent control, energy production and storage systems are causing a sharp increase in the need for dynamic management of power flows, which requires an adaptive reconfiguration of the naval energy architecture [10].

The evolution of the Naval Power System (NPS) led to the implementation of the Integrated Power System (IPS), which represents an advanced architecture consisting of a set of functional modules and standardized design processes.

In the navigation cabin, equipment such as radar, ECDIS systems and communication systems must operate at the highest possible efficiency to reduce the ship's energy consumption [11]. The following are taken into account: power factor; standby power consumption; durability and cyclic efficiency; monitoring and control of energy consumption; performance under variable load conditions; electromagnetic compatibility (EMC). The electromagnetic environment is dependent on the density of equipment on board; on the electro-energetic parameters of the equipment (frequency bands, powers, modulation types, etc.); on the intensity of the electric and magnetic field on board so that they are as small as possible and characterize the electromagnetic signature of the ship which can change [12].

For the far-field area, the power density for the antennas is calculated using Eq. (1) [13]:

$$P_d = \frac{P_E \cdot G}{4 \cdot \pi \cdot d^2} \quad (1)$$

where:

- P_d – power density (W/m^2);
- P_E – average or maximum transmitter power (W);
- G – antenna gain;
- d – distance from the antenna (m).



The antenna gain (G) is given by Eq. (2):

$$G = \frac{4\pi}{\alpha_o \cdot \alpha_v} \quad (2)$$

where:

- α_o / α_v – the opening angle in the horizontal / vertical plane (at $-3dB$) of the antenna directivity characteristic (radians);

The electric field strength at distance d from the antenna is given by Eq. (3):

$$E = \sqrt{P_d / Z_0} \quad (3)$$

where:

- E – electric field strength (V/m);
- Z_0 – the characteristic impedance of the open medium (120π or 377Ω);
- P_d – power density (W/m^2).

For the near-field area, the power density along the propagation axis for an antenna with circular or rectangular effective area is calculated using Eq. (4):

$$P_d = \frac{P_E \cdot G}{4 \cdot \pi \cdot d_{ad}^2} \cdot F_{ca} \quad (4)$$

where:

- P_d – power density (W/m^2);
- P_E – average or maximum transmitter power (W);
- G – antenna gain;
- d_{ad} – the distance from the antenna to the far field, $d_{ad} = \frac{2D^2}{\lambda}$, where λ is the wavelength;
- F_{ca} – the antenna near-field correction factor.

The characterization of the electromagnetic environment on board a ship is carried out based on several technical and operational factors: the type of equipment used - electroenergetic, electromechanical and electronic; the density of transmitters and their technical specifications, such as power level, modulation module, operating frequency, duration and pulse repetition frequency.

The characteristics of maritime navigation and radiocommunication equipment and systems are presented in Table 1. They are in accordance with the IEC 60945 standard.

Table 1. Characteristics of equipment installed on board a seagoing vessel.

Frequency band	Equipment type	Receiver sensitivity	Transmitter power
1525 – 1544 MHz	Marched	0.03 $\mu V/m$ (-167 dBW)	receiver
490 - 515 kHz	NAVTEX	2 $\mu V/m$	receiver
1575.42MHz $\pm 1.023MHz$	GPS	0.07 $\mu V/m$ (-160 dBW)	receiver
415 – 535 kHz	Radiotelegraphy (MF)	50 $\mu V/m$	150W
1605 kHz – 3.8 GHz		25 $\mu V/m$	400W
4 – 27.5 MHz	Radiotelegraphy and radiotelephony (HF)	25 $\mu V/m$	1500 W power
156 – 165 MHz	Radiotelephony (VHF)	2 $\mu V/m$	25W



2.9 – 3.1 GHz	S-band radar	1.4 μ V/m (-134 dBW)	25 kW (pulse)
9.3 – 9.5 GHz	X-band radar	1.4 μ V/m (-134 dBW)	25 kW (pulse)
9.3GHz – 9.5GHz	Jump	- 80 dB	400mW
1626.5MHz – 1646.5MHz	Marched	broadcaster	25W

3. Ship's energy management system

The Energy Management System (EMS) is becoming a critical component in the operation of modern commercial ships, representing a set of integrated technologies and processes that aim to optimize on-board energy consumption and greenhouse gas emissions.

The components of the energy management system are: energy consumption monitoring; propulsion and speed optimization; energy recovery systems; predictive maintenance.

The Integrated Platform Management System (IPMS) performs automation of the integrated deck and engine system platform for operational efficiency. The integration of all systems on board ships can optimize the operational capacity of interconnected equipment. The IPMS is located in the engine control room, in the ECC (main engine control point), and the secondary location is on deck in the navigation cabin. The IPMS is interfaced with the Auto Power Management System (APMS) and shares data with the Integrated Navigation System (IBS) [14], [15]. For the implementation of the IPMS, the following are considered: the Automatic Data Acquisition System (ADAS); the Degaussing System [16], [17]; the Integrated Power System (IPS) [18]; the sustainability of maritime transport.

The power electronic circuit block (Power Electronics Building-PEBB) has the role of achieving reductions (of energy losses, dimensions, costs,) using high-density, modular, reliable power electronic converters that can support a larger volume of load and that can allow the increase of the system of which they are a part, under high voltage and current conditions. As applicability they are used in control and protection architectures of power converters based on PEBB in naval installations - Table 2 and Table 3 [19].

Table 2. Electrical characteristics of navigation equipment

Equipment	Supply voltage	Nominal power	Conformity / Standard	Observations
Radar	230V AC	2kW	IMO, SOLAS	Differential protection
ECDIS (Furuno)	24V DC	150W	IMO, SOLAS	Electronic nautical chart display system
AIS	12V DC	-	IEC 61162-1 (NMEA 0183)	Low power consumption, NMEA 0183 compatible
Gyrocompass	115V AC / 400Hz	-	-	$\pm 0.5^\circ$ accuracy, autopilot integration

Table 3. Electrical characteristics of the emergency generator, UPS and batteries

Source	Capacity/power	Autonomy	Observations
UPS	10 kVA	~30 minutes	For critical equipment (Radar, ECDIS, AIS)



Auxiliary generator	50 kW	-	Ensures full power supply to the control deck in case of failure
Backup batteries	200Ah	~1 hour	For emergency systems (lights, communications, AIS, etc.)

The ship's main transformer load (kVA) and voltage swing was presented using a line chart (Fig. 1). The line highlights the load level (in kVA). At 60 kVA is the nominal capacity, ~ 45 kVA (75%) represents the load in normal operation. The range remains between +5% and -5% of the nominal value.



Fig. 1. Transformer charging

The electrical power consumption values of the mandatory equipment on board are presented in Table 4 – with the assumption that the consumption values for equipment that operates continuously (ECDIS, AIS, Gyrocompass) remain constant and the radar is turned on in the intervals 0 – 2h, 4 – 6h and 6 – 9h.

Table 4. Power consumption of navigation equipment

Time slot	Radar (kW)	ECDIS (kW)	AIS (kW)	Gyro (kW)	Hourly total (kW)
0 – 1 hours	2.00	0.15	0.05	0.05	2.25
1 – 2 hours	2.00	0.15	0.05	0.05	2.25
2 – 3 hours	0.00	0.15	0.05	0.05	0.25
3 – 4 hours	0.00	0.15	0.05	0.05	0.25
4 – 5 hours	2.00	0.15	0.05	0.05	2.25
5 – 6 hours	2.00	0.15	0.05	0.05	2.25
6 – 7 hours	2.00	0.15	0.05	0.05	2.25
7 – 8 hours	2.00	0.15	0.05	0.05	2.25
8 – 9 hours	2.00	0.15	0.05	0.05	2.25
9 – 10 hours	0.00	0.15	0.05	0.05	0.25
10 – 11 hours	0.00	0.15	0.05	0.05	0.25
11 – 12 hours	0.00	0.15	0.05	0.05	0.25

Also we have created a chart, where the columns represent the total consumption (kW) in each hour. On the horizontal axis - X - the hourly intervals appear, and on the vertical axis - Y - the value of the active power (kW). Each # symbol represents 0.25 kW (Fig. 2).

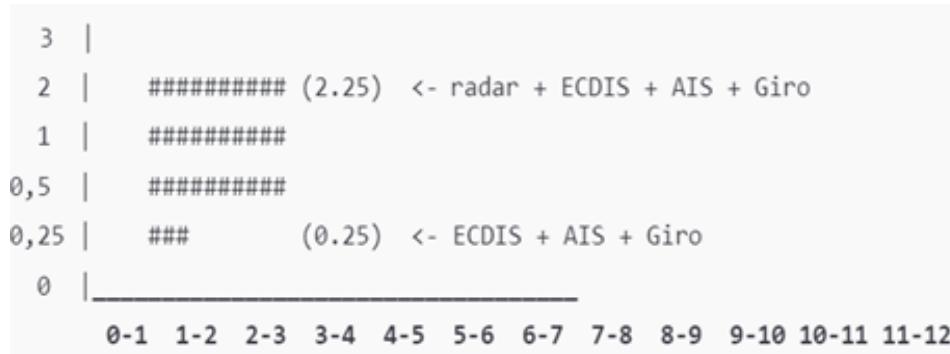


Fig. 2. Power consumption of navigation equipment

- Intervals with **2.25 kW** (e.g. 0 – 1h, 1 – 2h, 4 – 9h) have the radar on.
- **0.25 kW** intervals (e.g. 2 – 3h, 3 – 4h, 9 – 12h) have only ECDIS, AIS and Gyrocompass (Fig. 3).

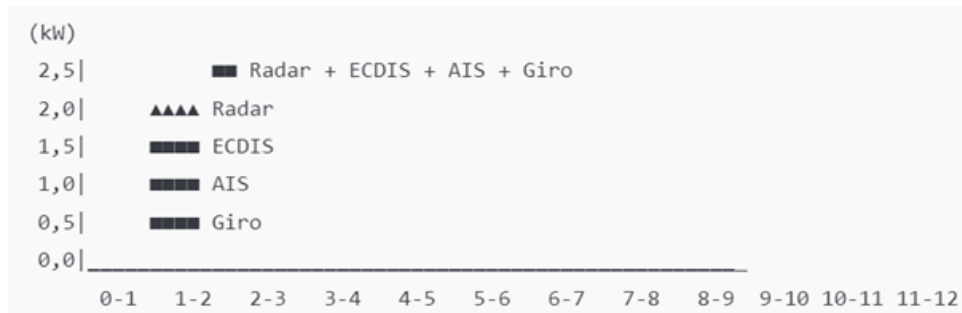


Fig. 3. Power consumption of individual and collective navigation equipment

The graphs show us the periods of peak consumption (Radar is on), the intervals of minimum consumption (ECDIS, AIS, Gyrocompass are active) and how we can optimize energy consumption.

4. Artificial intelligence in navigation management

The analysis of electrical signals was carried out using gyrocompass systems as an examination using AI techniques. The work provides a new methodology for analyzing gyrocompass signals [20]. By using advanced machine learning techniques and signal processing algorithms, it becomes possible to extract valuable information from electrical signals, allowing improved management of navigation systems [21], [22].

The use of gyrocompasses in navigation management plays a critical and vital role in ensuring the accuracy and reliability of ship positioning. Conventional methods often have limitations in terms of accuracy and efficiency, which can compromise overall navigation performance. One of the key challenges in navigation management is the ability to effectively analyze and interpret the electrical signals generated by gyrocompasses. These signals contain valuable information about the ship's direction and rotation, which are essential for accurate determination of position, course, and speed [23].

To address these challenges, an advanced and intelligent approach is needed that leverages the power of artificial intelligence (AI) and machine learning techniques.



Analyzing electrical signals from gyrocompass systems using AI offers several potential benefits. First, it enables real-time monitoring and predictive analytics, allowing for early detection of anomalies or failures in gyrocompass systems. By promptly identifying and addressing these issues, navigational safety can be significantly improved. Second, AI algorithms can be used to accurately extract key features and patterns from electrical signals, leading to accurate information about the ship's heading and positioning. This enables optimized route planning, fuel efficiency, and overall reduction in operational costs. In addition, integrating AI-powered gyrocompass analysis with other navigation systems, such as global navigation satellite systems (GNSS), can improve the reliability and robustness of positioning solutions, especially in challenging environments where GNSS signals may be degraded or unavailable [24].

Ethical considerations, such as data privacy, also need to be addressed when implementing AI-based navigation management solutions. Incorporating cybersecurity into navigation systems facilitates the creation of stronger and more resilient systems capable of withstanding potential cyberattacks. The implementation of this technology serves to protect essential navigation operations, including but not limited to ship location, route planning, collision avoidance, data modification or disruption [25].

The behavior of a gyrocompass in real time can be modeled using an interactive educational application implemented in Python. The program can: model a ship equipped with a gyrocompass, which can change direction depending on the rate of turn; graphically display the ship's actual direction using an arrow indicating the orientation angle relative to North; include a continuous position update and graphical display in real time, providing the user with a clear and intuitive representation of the direction.

A series of phases and steps are required:

1. Data preparation
 - Step 1: Collect electrical signals and the corresponding labeled data.
 - Step 2: Divide the data set into three subsets: training, validation, and testing.
2. Preprocessing
 - Step 1: Apply noise reduction techniques to the electrical signals.
 - Step 2: Perform signal filtering and remove nonsense values, if necessary.
3. Feature Extraction
 - Step 1: Extract relevant features from preprocessed electrical signals.
 - Step 2: Use techniques and methods such as time or frequency domain analysis.
4. Model Training
 - Step 1: Initialize the AI model architecture (e.g., artificial neural network).
 - Step 2: Define optimization parameters.
 - Step 3: Train the model using the training dataset.
 - Step 4: Iteratively adjust the model arguments to minimize the loss function.
5. Model Evaluation
 - Step 1: Evaluate the trained model using the validation dataset.
 - Step 2: Calculate performance metrics such as accuracy and precision.
6. Model Testing
 - Step 1: Use the trained model to analyze electrical signals
 - Step 2: Obtain estimated navigation parameters (e.g., ship heading, rotation).
7. Performance Evaluation
 - Step 1: Compare the AI-enabled analysis with traditional methods.
 - Step 2: Calculate performance metrics on the test dataset.
 - Step 3: Evaluate the accuracy, efficiency, and reliability of the AI model.
8. Integrate cybersecurity considerations
 - Step 1: Implement secure data handling practices (e.g., encryption, access control).
 - Step 2: Include threat detection and prevention mechanisms.
9. Monitoring and Continuous Improvement



- Step 1: Monitor the AI-enabled analysis framework for potential cyber threats.
- Step 2: Implement incident response measures to address any identified security incidents.
- Step 3: Continuously improve the analysis framework based on feedback and new data.

The program can be extended to simulate more complex conditions, such as integrating sea currents, wind, or other factors that influence the direction of the ship. This flexibility makes it a valuable tool for educational and research purposes.

5. Simulation of data acquisition and transmission from navigation equipment

To virtually replicate the process of collecting information from various navigation devices, such as the radar, ECDIS, AIS system, or gyrocompass, and subsequently transferring it to a storage and processing system, the Python programming language can be employed. By integrating the pymysql library, it is possible to establish a direct connection with a MySQL database, enabling query execution, insertion of new records, and real-time data updates. Such a simulation not only provides a representation that closely mirrors the real-world behavior of the equipment in operation but also offers a valuable testing environment for verifying and optimizing the data flow prior to actual implementation on a vessel.

To enable interaction between the Python application and the database, we will define a dedicated function for the connection process. This function will establish the necessary authentication parameters, such as the server name (host), username (user), access password (password), and the database name (database). Once called, the function will initialize the connection using the pymysql library, verify that it has been successfully established, and return the connection object, which can later be used to execute queries, insert new data, or update existing information. In case the connection fails, the function can include an error-handling mechanism to display appropriate messages and prevent the program from terminating unexpectedly. The dedicated function defined for the connection process:

```
python
import pymysql.cursors
def connect_to_database():
    return pymysql.connect(host='your_host',
                           user='your_user',
                           password='your_password',
                           database='your_database',
                           cursorclass=pymysql.cursors.DictCursor)
def send_data_to_database(table, data):
    connection = connect_to_database()
    try:
        with connection.cursor() as cursor:
            columns = ', '.join(data.keys())
            placeholders = ', '.join(['%s'] * len(data))
            sql = f"INSERT INTO {table} ({columns}) VALUES
({placeholders})"
            cursor.execute(sql, list(data.values()))
            connection.commit()
    finally:
        connection.close()
```

To virtually reproduce the process of acquiring essential information about the ship's heading and orientation, we will simulate the reading of data generated by the gyrocompass and the magnetic compass, after which these values will be automatically transmitted to a database for storage and



further analysis, thus ensuring a continuous and reliable flow of information similar to that of a real navigation system. The acquisition of data generated by the gyrocompass and the magnetic compass:

```
python
def read_compass_data():
    # Simulating reading data from gyrocompass and magnetic compass
    = {
        'gyro_heading': 270, # grade
        'magnetic_heading': 272 # grade
    }
    send_data_to_database('compass_data', data)
read_compass_data()
```

In conclusion, this simulation framework demonstrates how Python, combined with the pymysql library, can effectively emulate the acquisition and transmission of navigation equipment data, providing a realistic and reliable environment for testing, validating, and optimizing data flow processes before their deployment on an actual vessel.

The advanced analysis of electrical signals generated by gyrocompass systems, carried out through artificial intelligence, offers substantial benefits within the field of maritime navigation. By employing this technology, it becomes possible to perform continuous, real-time monitoring of critical equipment parameters, as well as predictive assessments capable of identifying potential malfunctions or deviations from normal operation at an early stage. This approach creates the conditions for prompt interventions and the prevention of major failures.

Through the application of sophisticated AI algorithms, electrical signals can be processed in such a way that essential features and recurring patterns are extracted with precision, leading to highly accurate information regarding the vessel's heading and orientation. This increased accuracy directly contributes to optimized route planning, improved fuel efficiency, and, consequently, a reduction in overall operational costs.

The integration of AI-assisted gyrocompass analysis with data from other navigation systems particularly with information provided by Global Navigation Satellite Systems (GNSS), significantly enhances the reliability and robustness of positioning solutions. This capability is particularly valuable in challenging scenarios where GNSS signals may be degraded or unavailable, such as in polar regions, congested ports, or under severe weather conditions.

The data acquisition process begins with the collection of electrical signals produced by the onboard gyrocompasses, recorded over predefined time intervals and under various navigation conditions from calm seas to rough waters and complex vessel maneuvers.

The subsequent processing and interpretation stage is carried out using diverse AI methodologies, including decision trees, support vector machines (SVM), convolutional neural networks (CNN), and recurrent neural networks (RNN) trained through deep learning techniques. These models are trained on labeled datasets, where the desired outputs are well defined, in order to identify relationships and correlations between the acquired signals and the relevant navigation parameters.

Once trained, the models are deployed to analyze and interpret electrical signals in real time, ensuring a continuous flow of actionable information for onboard operators. The performance of each model is validated both against the training datasets and on independent test sets, to ensure their adaptability and robustness in real-world operational scenarios.

6. Conclusions

The paper analyzes the energy optimization, intelligent monitoring and security of naval power systems, by integrating emerging technologies such as artificial intelligence. The implementation of intelligent digital solutions, based on predictive models and advanced signal analysis, can substantially increase the operational efficiency, reliability and sustainability of maritime navigation systems.



The analysis and prediction of signals from navigation equipment (gyrocompass, radar, GPS, AIS, ECDIS) can be achieved using tools and algorithms from the field of machine learning. The use of AI leads to improved detection accuracy, reduced reaction time in alerting systems and a superior predictive capacity compared to traditional methods.

Alarm management and predictive maintenance systems can be developed, with a direct impact on increasing the level of safety in maritime operations. The predictive models and proposed optimization strategies contribute to reducing energy consumption on board, leading to significant fuel savings and lower operational costs.

The use of predictive algorithms allows maintenance to be planned based on the actual condition of the equipment, minimizing costly interventions and extending the life of components.

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