Calculation of the Electricity Production Potential of a Naval Wind System

Mircea PREDA and Gheorghe SAMOILESCU

***Abstract*—The use of renewable energy sources on board ships is one of the solutions for reducing pollution generated by maritime transport. Considering it as one of the many solutions for the transition to "zero" emission ships, we studied the possibility of installing a wind energy conversion system on ships already in operation. The current electricity production system is transformed into a hybrid system, which will allow part of the energy consumed to be green energy, clean energy, and the energy produced in the classic system to be obtained with a much lower specific fuel consumption. Monitoring the daily electricity consumption and recording the values for the parameters of renewable energy sources for the periods and voyages of the ships allowed calculations to be performed determining the potential for electricity production from renewable sources and demonstrated the viability of the chosen solution. The results obtained highlight the fact that by installing the wind system, significant reductions in the consumption of fuel used for electricity production as well as potential reductions in fuel consumption in the propulsion system can be achieved.**

***Index Terms*—consumption reduction, cyclonic flow, specific fuel oil consumption, wind collector, wind system.**

I. Introduction

The United Nations, through its specialized structure – the International Maritime Organization (IMO), imposes strict rules on maritime transporters for the protection of the marine environment and beyond. Through its emissions control program, the IMO has established that, by 2030, carbon dioxide emissions should be reduced by 20%. These objectives are not easy to achieve and for this, sustained joint activities of shipowners and shipbuilders are needed to support and develop research in the field, in order to find effective solutions for environmental protection [1].

In terms of air quality, in 2016, the IMO imposed a stricter global limit of 0.5% (down from 3.5%) on the level of emissions of sulfur oxides into the atmosphere, which came into force on 1 January 2020. In order to comply with these pollution regulations, maritime transporters could choose between using more expensive fuels with a low sulfur content within the imposed limits or continuing to use fuels with a high sulfur content but installing and permanently using exhaust gas cleaning facilities. These rules, imposed both globally by the IMO and by certain local administrations regarding emissions of sulfur oxides, nitrogen oxides and particulates into the atmosphere, led to the search for solutions to reduce or even eliminate these emissions [2].

The approach of searching for solutions to bring a contribution of "clean/green" energy produced by wind or photovoltaic systems into the ship's electrical energy system is welcome for reducing greenhouse gas emissions.

In the research process to find solutions for implementing renewable energy sources on board commercial ships for electricity generation, we came to the conclusion that for the type of ship studied, the cyclonic flow wind turbine represents the optimal solution for converting wind energy into electricity.

In the hereby article, the energy potential of a wind system is studied based on data recorded and processed during voyages carried out by four ships of the same category, two of them built in 2019 and the other two in 2021.

To determine the generation potential of a wind system installed on board a ship, we have presented the features of the existing on board anemometer, equipment which continuously monitors the parameters of the movement of air masses (wind) acting on the moving or stationary ship and the way in which these are recorded, as well as the method of calculating the basic parameters.

In the next chapter, we presented the construction data, the characteristics of the cyclonic flow wind turbine and wind collector and its operating mode. For adaptation and installation on board the ship, the construction parameters of the turbine were calculated according to the construction characteristics of the ship, resulting in the dimensions of the turbines that can be installed on board these ships. Based on the resulting dimensions, we calculated the power of such a turbine determined for a speed of 14 m/s. In the fourth chapter, the data collected during the march between Paranagua / Brazil and Fujairah UAE was interpreted and calculations were performed to determine the energy potential of the system for one-hour intervals during the analyzed period. Due to lack of space, the data from August 4, 2025 was used for presentation. The data obtained was compared with the consumption values recorded in the corresponding intervals, demonstrating the viability of the solution regarding the contribution of green energy to the electricity production system on board the ship.

As a justification for choosing this type of wind turbine, the additional benefits that the installation of a wind system of a certain configuration on board can bring to the propulsion system by improving the aerodynamic coefficient of the ship were presented.

M. PREDA is with the Military Technical Academy "Ferdinand I", Bucharest, Romania (email: mirceapreda@yahoo.com)

G. SAMOILESCU is with the Naval Academy "Mircea cel Bătrân", Constanta, Romania (email: samoilescugheorghe@yahoo.com)

Digital Object Identifier 10.32754/JMT.2026.1.18

This paper aims to bring attention to the idea of using renewable energy sources on board ships in operation by making minimal modifications that do not affect the ship's structural integrity or its stability [3].

II. Collection and Interpretation of Data Provided by Equipment Installed on Board the Ship

A. Anemometer & Anemoscope

The on-board determination of the (relative) wind speed and direction is done with a wide variety of mechanical, electrical or electronic devices, depending on the ship type, generically called anemometers. All anemometers provide an average speed value related to a time interval, short or long, but never the instantaneous speed.

The Anemometer & Anemoscope equipment installed on the standard deck provides constant information on wind direction and speed. The Anemometer & Anemoscope provides relative values of wind direction and speed, these being the vectorial resultant between the actual wind direction and speed on the one hand and the ship's direction and speed on the other. In practice, the data provided is the data of interest in the present study. The recorded parameters are real movement parameters of the air masses acting on the wind turbines installed on board the ship.

The Anemometer & Anemoscope installed on board the ship is of the cup anemometer type and has a rotor with three rotating cups. It has the following characteristics [4]:

- Wind speed measurement range 0 ~ 60 m/s or 0 ~ 116 knots (minimum starting wind speed 2 m/s)
- Wind direction measurement range 0º ~ 360º
- Data display:
  - o Speed: digital display of wind speed value in m/s or knots and transmission of analog signal 4 ~ 20 mA to data recording equipment
  - o Direction: digital display of angle value and direct indication of wind direction through a system of 36 LEDs, as well as transmission of analog signal 4 ~ 20 mA to data recording equipment
- Accuracy:
  - o speed up to ± 0.01 m/s
  - o direction up to ± 1%
- Resolution
  - o Speed: 0.1 m/s
  - o Direction: 3º

Data is saved in ".csv" format (Fig. 1)

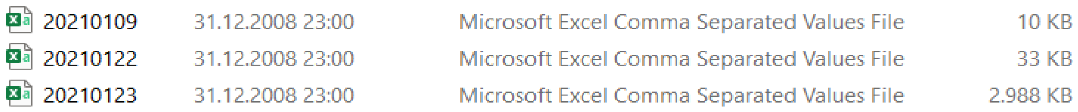

Figure 1. Data saved by the anemometer in .csv format

The systems installed on board the ship provide and save data on wind direction at one second intervals. In Fig. 2, the values recorded on June 26, 2021 at 00:00 can be seen: minute 0, seconds 5, 6, 7 and so on.

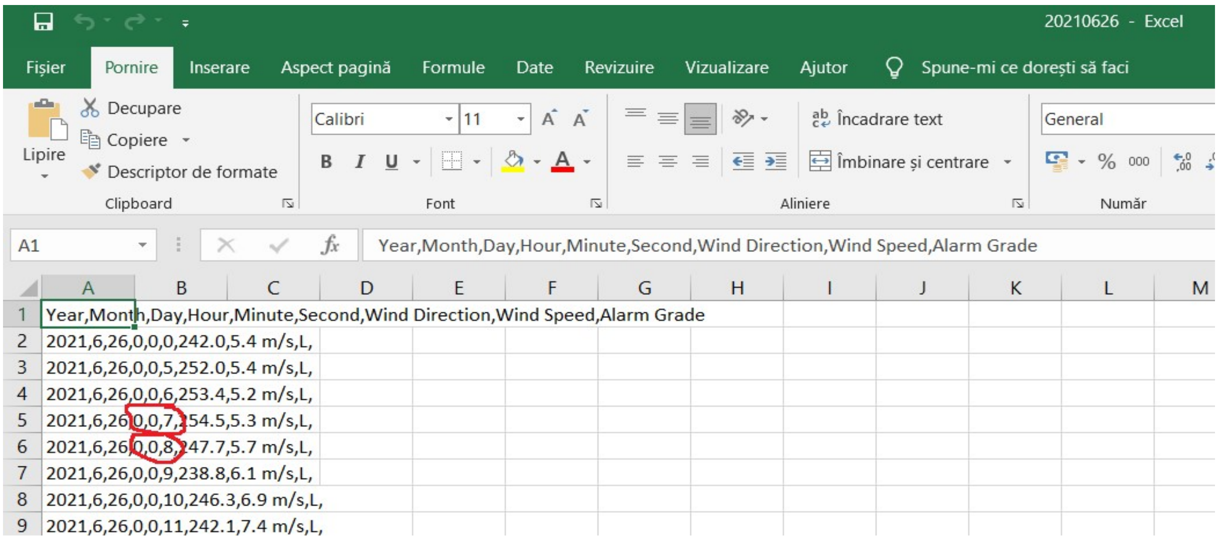

Figure 2. Data saved by the anemometer at one second intervals

B. Average Wind Speed

To study and characterize the wind resource in a given place, the minimum time interval adopted for systematic measurements is 10 minutes [5].

Starting from the data provided at one second intervals, for the simplification of subsequent data, we will calculate the average speed for a ten-minute interval. We will denote this speed by v_e (elementary average speed).

To determine the power that can be generated by a turbine, an estimate of the wind speed at the height h of the turbine collector is needed, using the data relating to the wind speed recorded by the anemometer located on the standard deck, it being known that the wind speed increases with height above sea level [6].

 Digital Object Identifier 10.32754/JMT.2026.1.18

A good approximation is achieved by using the following logarithmic relationship:

$$v = v_{ref}\left(\frac{h}{h_{ref}}\right)^{\alpha}, \quad (1)$$

where v is the wind speed at the height h of the rotor, v_{ref} is the wind speed at the height h_{ref} of the anemometer, and α is the power exponent, which can be determined based on the following relationship proposed in 1978 by Justus:

$$\alpha = \frac{0.37 - 0.088 \cdot \ln\left(v_{ref}\right)}{1 - 0.088 \cdot \ln\left(\frac{h_{ref}}{10}\right)} \quad (2)$$

Starting from the speed indicated by the anemometer as a reference speed and the height difference between the installation location of the anemometer and the height at which each row of turbines is installed, we can determine the wind speed acting at the level of the cyclonic flow wind turbine and wind collector.

From the ship's construction plans we note that the anemometer is installed at an absolute height of 35.2 m (from the keel line) which determines a relative height of 24.8 m above the waterline when the ship is sailing in ballast (the ship without cargo) and of 21.9 m when the ship is loaded to maximum capacity.

We will take into account the sailing conditions of the ship in ballast, so we will take into account the reference height $h_{ref} = 24.8$ m and the corresponding heights of each row of wind turbines (numbered from the top row to the bottom) $h_1 = 20$ m, $h_2 = 17$ m and $h_3 = 14$ m.

To highlight the difference in the value of the speed corresponding to each height of the turbine set compared to the reference speed, a wind speed of 14 m/s was taken into account.

By introducing the values of the relative speed, the relative height and the heights of the turbine set into (1) and (2), the following values of the speeds corresponding to the height of each turbine set will result:

Reference speed	**14 m/s**
Reference height	28,8 m
Power exponent	0,14973
Level 1 height	20
Level 2 height	17
Level 3 height	14
Level 1 speed	13,55626
Level 2 speed	13,23037
Level 3 speed	12,85128

The values obtained confirm what we knew, namely that wind speed increases with altitude.

If we denote by $v_i(t)$ the instantaneous wind speed, the average value of the speed over a period of time T is calculated with the well-known relationship from Mathematical Analysis:

$$v_m = \frac{1}{T}\int_0^T v_i(t)\,dt \quad (3)$$

The average can be hourly, daily, weekly, monthly or annual depending on the reference interval T. Usually, the basis of analysis is the hourly average, from which the other average values can be determined later [7].

In practice, as shown above, the instantaneous wind speed is not known and, then, the average speed is calculated using a certain number N of average values calculated over time intervals Δt, the duration of which depends on the type of device used. If, for example, average wind speed values are available for 10-minute intervals, it is obvious that 6 values will be used for the hourly average. In general, the average wind speed value is calculated, in practice, using the relationship:

$$v_m = \frac{\Delta t}{T}\sum_{i=1}^{\frac{T}{\Delta t}} v_i = \frac{1}{N}\sum_{i=1}^{N} v_i \text{ e} \quad (4)$$

which is an approximation of the above integral, an approximation all the better the smaller the time interval Δt is. Considering the fact that we have recordings at an interval of one second, the average speed resulting from the calculations performed on board the ship will have a value very close to the real one.

C. Average Cubic Velocity

The average cubic velocity is defined as the third root of the average cube of the instantaneous velocity [5]:

$$v_{m,3} = \left(\frac{1}{T}\int_0^T v_i^3(t)\,dt\right)^{\frac{1}{3}} \quad (5)$$

The importance of the cubic mean speed is obvious given that the power of a wind power plant is proportional to the cube of the wind speed [8].

It should be noted that the difference between v_m and $v_{m,3}$ depends on the irregularity of the wind. In fact, $v_{m,3}$ is greater than v_m, the more the instantaneous speeds are different from their average value.

This fact can be illustrated with the following example.

- Let's consider two different situations for which we have three speed values:

- constant wind: 5, 5, 5 m/s → $v_m = 5$ m/s, $v_{m,3} = 5$ m/s;
- irregular wind: 2, 5, 8 m/s → $v_m = 5$ m/s, $v_{m,3} = 5.99$ m/s.

III. Wind Turbine with Cyclonic Flow and Navalized Wind Collector

A. Characteristics of the Cyclonic Flow Wind Turbine and Wind Collector

The novelty of this type of turbine theorized and presented by the inventor Adriano Pellegri, is represented by a new type of stator and is called a "cyclonic flow turbine" because the rotor is driven by a self-sustained movement of the fluid (air) in the form of a vortex, developed inside the stator and continuing in the cylindrical space of the rotor delimited by it [9].

The stator is formed by two identical truncated cones (Fig. 3.a), or circular surfaces, which have a slope towards the inner side.

The truncated coned have an outer radius of $2R$ and an inner radius of r. The two truncated cones are arranged at a

Digital Object Identifier 10.32754/JMT.2026.1.18

certain distance (in the given situation $D\times4$) each of them constituting the bases at the bottom and at the top of the structure. They are rigidly connected to each other by a set of vertical walls (Fig. 3.b). The walls have a curved section in the shape of a circular arc, are arranged radially around the inner edge of the truncated cone, and spaced equally from each other, reaching outwards to a distance R from the central axis of the stator [10].

On the outer circumference with radius $2R$ and along the circle with radius R (drawn by the outer edge of the vertical walls) on the surface of the two stator bases, sets of guide rails are fixed, which have the role of supporting and guiding at the bottom and at the top of a mobile element called *COLLECTOR* (Fig. 3.c), in order to be able to rotate freely around the central part of the stator, thus following the changes in wind direction [10].

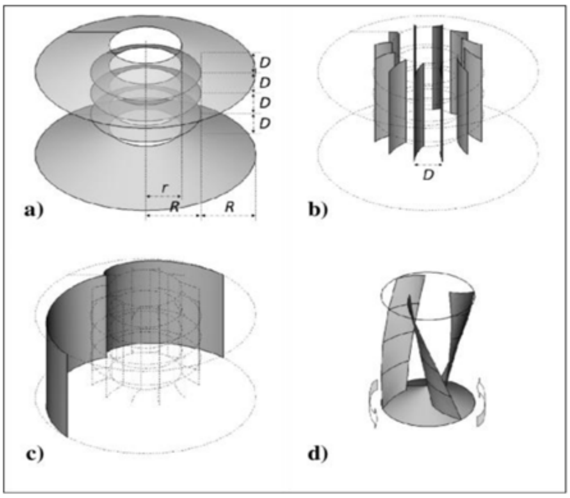

Figure 3. Components of a cyclonic flow wind turbine. a) horizontal stator elements, b) vertical stator walls, c) wind collector, d) rotor

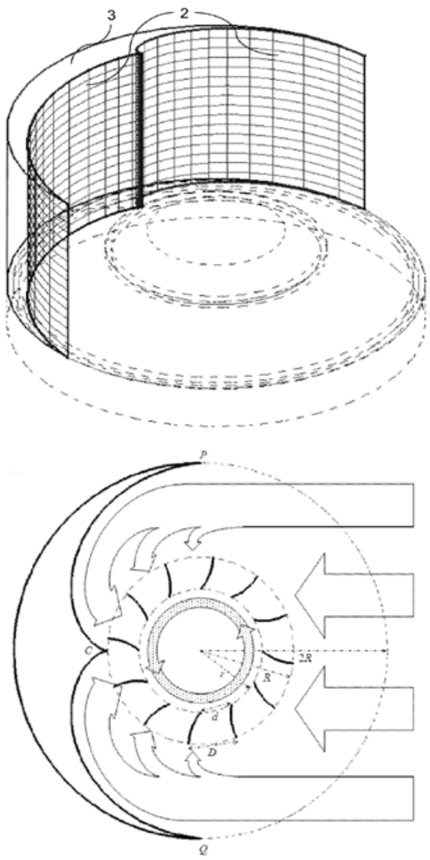

Figure 4. Wind collector and how to direct the airflow to the stator

The collector is composed on the outside of a vertical wall 3 (Fig. 4) with a semicircular section with radius $2R$, and on the inside of a wall with a special cardioid Section II (Fig. 4), described by two symmetrical circular arcs that start from two diametrically opposite points on the circumference with radius $2R$ and meet in the middle of the cup created at a point placed on the circle with radius R, whose horizontal section has the following equation [7]:

$$\left[\left(x+R\right)^2+y^2-2a\left(x+R\right)\right]^2=4a^2\left[\left(x+R\right)^2+y^2\right] \tag{6}$$

In addition to the structure, three other truncated cones are placed coaxially with the structure, having the same inclination as the two bases, the inner radius r and the outer radius R (half of the outer radius of the base) (Fig. 3.a). These are arranged at equal distances and the inner radius r is kept constant.

There is no central axis in the inner space of the rotor in order to keep the space free for it to be occupied by the low-pressure core of the vortex [10].

The three helical blades of the rotor are mounted on the periphery of the rotor cylinder with the possibility of tilting/bending them along the circumference. The blades are attached at the bottom on a cone-shaped surface with an outer radius r and the same inclination as the base which also has the role of closing/completing the lower base of the stator, while the upper part is open and constitutes the air exhaust part from the rotor space Fig. 3.d.

The air exhaust from the rotor space is assisted/aided by an upward current created by the movement of air masses from outside the turbine (wind) which do not pass through the inside of the turbine, but above it.

In the turbine stator, by mounting the vertical walls and horizontal separator rings, 48 nozzle channels are formed which are characterized on the outside by the size "D" and on the inside by the size "d". "D" will be considered a scalar factor.

The ratio between the outer radius of the stator and the scalar D

$$D=2R\sin\frac{\pi}{12} \tag{7}$$

Choosing for this prototype a number of twelve vertical stator walls that delimit the rotor space, the coefficients that define the inner surface of the collector can be defined numerically as follows:

$$\alpha=\frac{5\sqrt{6}+\sqrt{2}}{4\sqrt{5}+1}\cdot D=1.492D \tag{8}$$

The following proportions also apply:

$$R=\frac{D}{2}\left(\sin\frac{\pi}{12}\right)^{-1}=\frac{\sqrt{6}+\sqrt{2}}{2}D=1.932D \tag{9}$$

$$\begin{aligned} r&=\sqrt{R^2-\left(\frac{D}{2}\right)^2}-\frac{D}{4}\left(1+\frac{\pi}{2}\right)=\\ &=\left[\sqrt{2+\sqrt{3}-\frac{1}{16}}-\frac{1}{4}\left(1+\frac{\pi}{2}\right)\right]D=1.273D \end{aligned} \tag{10}$$

$$d=2r\sin\frac{\pi}{12}=0.659D \text{ sau } d=\frac{r}{R}D \tag{11}$$

 Digital Object Identifier 10.32754/JMT.2026.1.18

B. Adaptation of the Cyclonic Flow Wind Turbine and Wind Collector to the Body of a 50,000 dwt Oil/Chemical Vessel

The distinction between HAWT and VAWT usually consists of the "anthropic" references to the Earth because the wind blows parallel to the Earth's surface, more correctly speaking, it must refer to the main direction of the flow lines. In the new turbine the airflow crosses the rotor in the axial direction like horizontal axis turbines. This is precisely what we considered when designating this turbine, the best choice for configuring a wind system on board ships. The fact that the direction of the airflow lines is changed from the horizontal to the vertical plane can determine the increase in the aerodynamic coefficient of the ship.

For the adaptation of the wind turbine with cyclonic flow and wind collector to the configuration and installation on board the ship that is the subject of the study (50,000 dwt oil/chemical tanker ships) the following were taken into account:

- the dimensions of the hull of a 50,000-dwt oil/chemical tanker, Hyundai, built in 2021
- the visibility angles in the navigation order according to the ship's documentation approved by the DNV Register of Naval Classification
- the need to ensure free spaces on the deck for the optimal operation of the ship during loading or unloading activities,

Taking into account the limitations set out above, we have considered the possibility of placing three rows of cyclonic flow turbines in front of the ship's castle on the portion corresponding to decks B and C, between the upper limit of the windows on deck A and the lower limit of the navigation deck, and across the entire front opening of the castle in width. We have at our disposal a surface 10 (ten) meters high and 24 (twenty-four) meters wide. From the analysis of the dimensions and visibility angles, we have come to the conclusion that the best option is to consider the installation of twelve cyclonic wind turbines arranged in three rows, the bottom row being shifted towards the bow by a distance equal to 3 R compared to the row above it, the third row being arranged in close proximity to the castle wall (Fig. 5) [11].

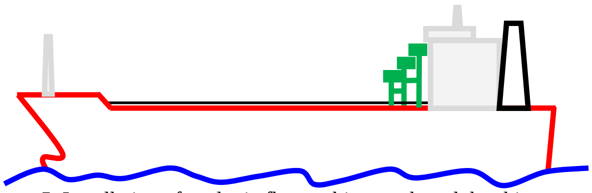

Figure 5. Installation of cyclonic flow turbines on board the ship

The space allocated to a turbine is $L = 6$ m și $H = 3.3$ m .

The maximum horizontal dimensions of the turbine are given by the dimensions of the turbine base and the wind collector, these being twice as large as the stator diameter, which determines the relationship:

$$4R \prec 6 \tag{12}$$

From the 6 m space allocated to a turbine, the space intended for turbine maintenance will be subtracted, which will determine that the value chosen for the scalar factor D is 0.7 m.

Applying the calculation formulas presented by the turbine inventor Adriano Pellegri, we will have:

$$R = 1.932D = 1.932 \cdot 0.7 = 1.3524 \text{ m}$$

Total turbine diameter = 5.41 m (13)

Stator height = 4D = 2.8 m

The maximum available power of a turbine at a wind speed $v = 14$ m/s . We enter the data $D = 0.7$ m and $v = 14$ m/s into the formula for calculating the power and the result is a maximum available power

$$P_e^{\max} = \frac{1}{2} q A_e v_e^3 = 4\left(\sqrt{6}+\sqrt{2}\right) q D^2 v_e^3 \tag{14}$$

$$\begin{aligned} P_e^{\max} &= 4(\sqrt{6}+\sqrt{2}) \cdot 1.25 \cdot 0.7^2 \cdot 14^3 \\ P_e^{\max} &= 15.455 \cdot 1.25 \cdot 0.49 \cdot 2744 \\ P_e^{\max} &= 25975.22 \text{ W} \\ P_e^{\max} &= 25.975 \text{ kW} \end{aligned} \tag{15}$$

The power coefficient determined from the CFD simulation for wind speed $v = 8$ m/s was [9] $C_p = 0.54$.

For $v = 14$ m/s we considered a decreasing power coefficient $C_p = 0.53$.

The power of an analyzed cyclonic flow wind turbine with an air duct opening $D = 0.7$ m at a wind speed $v = 14$ m/s will be:

$$P_{TVN} = C_p \cdot P_e^{\max} \tag{16}$$

$$P_{TVN} = 0.53 \cdot 25.975 = 13.767 \text{ kW} \tag{17}$$

In future calculations, the following will be taken into account:

$$P_{TVN} = 13.75 \text{ kW} \tag{18}$$

IV. Determining the Potential of the Wind System

A. Determining the Power of a Turbine with the Imposed Construction Data

Starting from the construction of the turbine with the stator having an external diameter different from that of the rotor, we need to see what is the relationship between the power corresponding to the external interception area of the stator and the power corresponding to the internal area of the stator or the area corresponding to the rotor.

D being the height of each flow sector, taking into account four overlapping sectors, the total external air interception area for this stator is:

$$A_e = 4R \cdot 4D = 8\left(\sqrt{6}+\sqrt{2}\right) D^2 \tag{19}$$

Denoting with v_e the wind speed (external speed, or inlet speed) and with $q = 1.25$ kg/m^3 the air density, the total available power $P_e^{\max}$ is expressed by the relationship:

$$P_e^{\max} = \frac{1}{2} q A_e v_e^3 = 4\left(\sqrt{6}+\sqrt{2}\right) q D^2 v_e^3 \tag{20}$$

The portion of the rotor blade that is pushed by the jet of a duct or in other words the internal incidence surface of each air duct is:

$$A_i = D^2 \cos\frac{\pi}{4} \cdot \frac{1}{\cos\varphi} = \frac{3}{4} D^2 \tag{21}$$

In the duct where the vertical side walls have the shape of an arc of a circle with a convergence angle between them of 30° (360°/12), the incoming air is subjected to an acceleration process through the tunnel effect, having the internal velocity, or air injection velocity, denoted v_i or each air duct

$$v_i = \frac{D^2}{A_i} v_e = \frac{4}{3} v_e \tag{22}$$

Each duct sector contributes to the total power to a different extent depending on the orientation of its inlet section with respect to the main wind direction. Summing the contribution of each stator duct sector, the total power injected into the rotor space is:

$$P_i^{\max} = 4\frac{1}{2}qA_i\cos\frac{\pi}{12}\cdot 4[\sin\frac{5\pi}{12}\left(v_i\sin\frac{5\pi}{12}\right)^3 + \\ +\sin\frac{\pi}{4}\left(v_i\sin\frac{\pi}{4}\right)^3 + \sin\frac{\pi}{12}\left(v_i\sin\frac{\pi}{12}\right)^3 = \\ = 9qA_iv_i^3\cos\frac{\pi}{12} \tag{23}$$

Substituting the values of A_i and v_i in (22) and (23) and taking into account (21) we get:

$$P_i^{\max} = 9qA_iv_i^3\cos\frac{\pi}{12} = 9q\frac{3}{4}D^2\cdot\left(\frac{4}{3}v_e\right)^3\cdot \\ \cdot\frac{\sqrt{6}+\sqrt{2}}{4} = 4\left(\sqrt{6}+\sqrt{2}\right)qD^2v_e^3 = P_e^{\max} \tag{24}$$

The power available in the interior of the rotor is equal to that intercepted by the stator in the assumption of a laminar flow. The losses due to air viscosity are mostly compensated by the increase in air density in the duct and are therefore negligible.

For a wind speed $v = 14$ m/s we enter the data $D = 0.7$ m in the formula for calculating the power

$$P_e^{\max} = \frac{1}{2}qA_ev_e^3 = 4\left(\sqrt{6}+\sqrt{2}\right)qD^2v_e^3 = \\ = 4\left(\sqrt{6}+\sqrt{2}\right)\cdot 1.25\cdot 0.7^2\cdot 14^3 = \\ = 15.455\cdot 1.25\cdot 0.49\cdot 2744 = 25975.22 \text{ kW} \\ P_e^{\max} = 25.975 \text{ kW} \tag{25}$$

The power coefficient determined from the CFD simulation for wind speed $v = 8$ m/s was [9] $C_p = 0.54$.

For $v = 14$ m/s we considered a decreasing power coefficient $C_p = 0.53$.

The power of a cyclonic flow wind turbine with an air duct opening $D = 0.7$ m at a wind speed $v = 14$ m/s will be:

$$P_{TVN} = C_p\cdot P_e^{\max} = 0.53\cdot 25.975 \\ P_{TVN} = 13.767 \text{ kW} \tag{26}$$

In future calculations, the following will be taken into account: $P_{TVN} = 13.75$ kW.

B. *Determining the Potential of the Wind System*

As previously established, the wind system is composed of 12 turbines arranged on three levels. A wind system with 12 wind turbines has a theoretical potential at a wind speed of 14 m/s of 165 kW

$$P_{sis} = 12\cdot P_{TVN} = 12\cdot 13.75 \text{ kW} \\ P_{sis} = 165 \text{ kW} \tag{27}$$

For the practical determination of the energy potential of the analyzed wind system, we will use the data recorded on August 4, 2025 during the Paranagua-Fujaireh voyage, a day when it was passing between Mozambique and the island of Madagascar (Fig. 6).

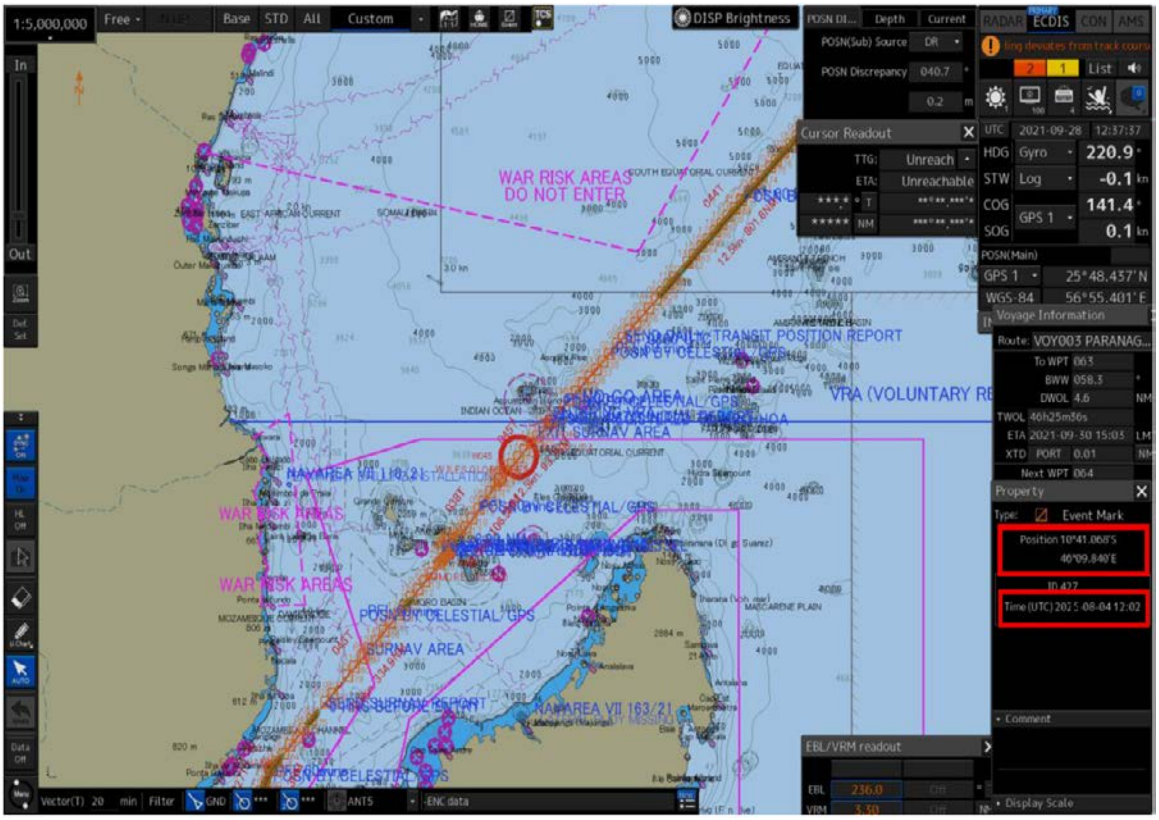

Figure 6. ECDIS capture taken on August 15, 2025 for the ship's position on August 4, 2025 at 12:00

For the 24 hours of August 4, 2025, 86400 sets of wind speed and direction values were recorded, one for each second. The elementary cubic mean speed was calculated for a 10-minute interval, resulting in a number of 144 elementary cubic mean speed values.

The 144 sets were grouped by six to calculate the hourly cubic mean speed. The 24 values obtained were introduced into the wind turbine power calculation formula to determine the wind turbine energy potential for each individual hourly interval, starting with the hourly interval 00:00 - 01:00 until the hourly interval 23:00 - 24.00.

$$P_e^{\max} = \frac{1}{2} q A_e v_e^3 = 4\left(\sqrt{6}+\sqrt{2}\right) q D^2 v_e^3 = \\ = 15.155\cdot 1.25\cdot 0.49\cdot v_e^3 = 9.466\cdot v_e^3 \text{ W} \tag{28}$$

$$P_{TVN} = 0.53\cdot 9.466\cdot v_e^3 \\ P_{TVN} = 5.01708\cdot v_e^3 \tag{29}$$

At the same time, the data on the electricity consumption for August 4, 2025 was also selected for the same time intervals.

The results of the calculations performed to determine the value of the average hourly cubic velocity, the electricity production potential of a turbine for each time interval, the system potential and the recorded consumption values were listed in Table I.

TABLE I. CONSUMPTION AND PRODUCTION POTENTIAL DATA OF THE WIND SYSTEM FOR AUGUST 4, 2025

Hourly interval	Average speed v_{m3}	Speed cube v^3	Turbine output		System output	Consumption	Percent
			Wh	kWh	kWh	kWh	
01:00	5.5	166.375	834.7167	0.83	10.02	350	2.86
02:00	5.6	175.616	881.0795	0.88	10.57	360	2.94
03:00	3.1	29.791	149.4638	0.15	1.79	355	0.51
04:00	5.4	157.464	790.0095	0.79	9.48	350	2.71
05:00	7.4	405.224	2033.041	2.03	24.40	345	7.07
06:00	8.6	636.056	3191.144	3.19	38.29	380	10.08
07:00	9.2	778.688	3906.74	3.91	46.88	370	12.67
08:00	10.2	1061.208	5324.165	5.32	63.89	380	16.81
09:00	10.3	1092.727	5482.299	5.48	65.79	420	15.66
10:00	9.1	753.571	3780.726	3.78	45.37	470	9.65
11:00	11.9	1685.159	8454.578	8.45	101.45	440	23.06
12:00	13.9	2685.619	13473.97	13.47	161.69	490	33.00
13:00	14.6	3112.136	15613.84	15.61	187.37	400	46.84
14:00	15.3	3581.577	17969.06	17.97	215.63	470	45.88
15:00	16.4	4410.944	22130.06	22.13	265.56	470	56.50
16:00	17.5	5359.375	26888.41	26.89	322.66	430	75.04
17:00	18.1	5929.741	29749.98	29.75	357.00	460	77.61
18:00	17.5	5359.375	26888.41	26.89	322.66	380	84.91
19:00	18	5832	29259.61	29.26	351.12	380	92.40
20:00	18	5832	29259.61	29.26	351.12	375	93.63
21:00	17.9	5735.339	28774.65	28.77	345.30	370	93.32
22:00	17.9	5735.339	28774.65	28.77	345.30	350	98.66
23:00	17.5	5359.375	26888.41	26.89	322.66	350	92.19
00:00	17.5	5359.375	26888.41	26.89	322.66	350	92.19
Total 04 August 2025					4288.64	9495.00	

As can be seen, the production potential of the wind system can cover 45% of the ship's daily electricity needs. This percentage varies greatly by hour, starting from a percentage of 0.5% in the time interval 00:02-03:00 when the wind speed was at the turbine start-up limit, up to a percentage of 98.66% in the time interval 21:00-22:00.

The production of the wind system in real conditions is observed to be neither constant nor does it cover the entire electrical energy requirement of the ship, which determines the need to use a main diesel generator in parallel to the composition of the ship's current power plant. Under these conditions, this diesel generator operates at a very low load regime, which determines a high specific fuel consumption per kW (SFOC) compared to the optimal specific fuel consumption, recorded at a load of 75% of the nominal power value [12].

We can also encounter the situation in which the average cubic wind speed has a certain value that determines higher production compared to the consumption at that moment, which would determine a loss of the potential for green energy production, this being limited to the consumption value

$$P_{TVN} = 5.01708\cdot v_e^3 \text{ W} \tag{30}$$

$$v_e = 22$$

$$P_{TVN} = 5.01708\cdot 10648 = 53422 \text{ W} \tag{31}$$

$$P_{SE} = 53422 \text{ W}\cdot 12 = 641064 \text{ W} \\ P_{SE} = 641 \text{ kW} \tag{32}$$

To eliminate these drawbacks, it is necessary to install on board the ship an electrical energy storage system consisting of battery sets to store any surplus electrical energy produced by the wind system at high wind speeds and especially to store the difference between the electricity necessary to cover consumption and the electricity produced by the diesel generator at optimal consumption operating mode [12].

V. POSSIBLE ADDITIONAL BENEFITS

Studying the data stored by the anemometer/anemoscope system, it is observed that during the journey, over 98% of its duration the relative wind direction (wind direction relative to the ship) is in the 345° - 15° sector. Under these conditions the ship faces a significant frontal resistance to forward movement generated by the wind direction and speed.

Fig. 7 shows a schematic representation of the air mass circulation, a diagram based on the graphs and information provided by the manufacturer of the anemometer/ anemoscope installed on board the ship in its installation and operation manual [4].

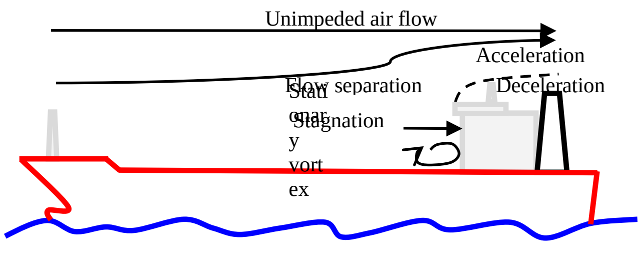

Figure 7. Circulation of air masses at ship level

It can be seen that in front of the ship's bow, there is a stagnation of air masses and the formation of stationary vortices. These lead to an increase in the ship's resistance to forward motion proportional to the third power of the wind speed

$$P_{op} = \frac{1}{2} q A_c v^3, \tag{33}$$

where A_c is the frontal surface of the ship's hull and v is the wind speed.

The construction and operation of the cyclonic flow wind turbine makes it suitable for installation and operation in front of the ship's hull. The fact that the air masses enter the turbine horizontally and are discharged vertically is an advantageous way for the air masses in front of the hull, which become stationary and cause an increase in forward resistance, to be directed over the hull towards the acceleration component of the air flow, thus significantly reducing forward resistance [13].

Using the dimensions from the constructive data of the turbine, we determine the corresponding surface area of a turbine A_t and then the surface area covered by the entire wind system A_s:

$$A_t = 5.4 \text{ m} \cdot 2.8 \text{ m} = 15.12 \text{ m}^2 \tag{34}$$

$$A_s = 15.12 \text{ m}^2 \cdot 12 = 181.44 \text{ m}^2 \tag{35}$$

The airflow whose incidence lines go towards the surface of the collectors of the eight turbines will be directed above the castle, reducing the forward resistance in proportion to this surface. The power of the collected airflow P_{fc}

$$\begin{aligned} P_{fc} &= \frac{1}{2} q A_s v^3 = \frac{1}{2} \cdot 1.25 \cdot 181.44 \cdot 14^3 = \\ &= \frac{226.8}{2} \cdot 2744 = 311169.6 \text{ W} \\ P_{fc} &= 311.17 \text{ kW} \end{aligned} \tag{36}$$

Considering the ship's accommodation as a rigid parallelepipedal construction without air leakage edges, the aerodynamic pressure coefficient [14] will be $C_{pe} = 1$, which means that the power of the air flow intercepted by the wind system is equal to the power that is assumed to be reduced from the total forward resistance of the ship P_{red}

$$\begin{aligned} P_{fc} &= P_{red} \\ P_{red} &= 311.17 \text{ kW} \end{aligned} \tag{37}$$

VI. CONCLUSION

Based on the need to reduce fossil fuel consumption, we have advanced the idea that renewable energy sources can be implemented in the electricity production system on current generation ships. In this study, we have analyzed the proposal for installing a wind energy conversion system consisting of twelve cyclonic flow wind turbines and a wind collector on board commercial transport ships in operation.

Due to its special characteristics, the fact that by its mode of operation it changes the direction of the flow lines of the air masses from the horizontal plane to the vertical plane made us consider that this type of wind turbine is the ideal solution for using wind energy on board the ship. By studying the invention project and the data presented by the inventor, we have identified the possibility of a double effect of installing this type of wind turbine. The first is the basic one, the one that determines its existence, namely electricity generation. The second one that we have identified and which is strictly related to the place and method of installation of a wind turbine assembly of this type is that of improving the aerodynamic coefficient of the ship, therefore decreasing the resistance to forward movement. The respective wind system was designed as a component part of an ecological naval power plant, a plant that represents an integrated system for converting renewable energies and storing electricity, interconnected with the ship's current power plant. From the results of the calculations carried out, which were based on data recorded during the journeys in different areas of the globe, and different periods, a few were selected and briefly presented in order to demonstrate that this solution is viable from several points of view, namely:

- it brings a contribution of green energy to the electricity generation system
- by connecting and working in parallel with the ship's diesel generator and the storage system, it significantly reduces the level of specific fuel consumption
- it increases the operational safety of the electrical system
- it reduces the ship's resistance to forward movement.

Different from the current main line of research directed at the development of new generations of environmentally friendly ships, this study aims to bring to attention the fact that renewable energy sources can also be implemented on ships in operation.

REFERENCES

[1] *** IMO Technical Measures in Reducing Greenhouse Gas Emissions from Ships: A Lloyd’s Register Perspective, 2009, F. Aronowitz

[2] *** The agreement to further protect the marine environment of the Mediterranean by establishing a Mediterranean Emission Control Area was concluded between the EU and Mediterranean countries, within the framework of the UN Barcelona Convention, in 2021. IMO 2022

[3] E. Bockmann, S. Steen, Department of Marine Technology, Norwegian University of Science and Technology (NTNU) - Second International Symposium on Marine Propulsion "SMP 11", Manburg, Jun. 2011

[4] *** Daeyang Anemometer & anemoscope Instructions Manual 2025

[5] *** Support information system for the design, implementation and control of hybrid energy farms - E-FARM)

[6] S. Masri, N. Mohamad, M. Hafeez, *Wind Speed Analysis at Nibong Tebal*, 2012, p. 4

[7] I. Stoian, *It System Support for Design, Implementation and Control of Eolian Energy Farms*, 2018

[8] ***ABB, *Technical application papers No.13 Wind power plants*, no. 13, p. 136, 2011.

[9] A. Pellegri, *The Complementary Betz’s Theory*, https://www.researchgate.net/ publication/336579973

[10] A. Pellegri, *Cyclonic flow wind turbine with statoric and rotoric elements* – WO 2018/073729 A1 – 2018

[11] ***Technical documentation tank type double tank oil / chemical class 50,000 dwt project 2789 MIPO DOCKYARD CO. LTD. ULSAN KOREA

[12] M. Preda, G. Samoilescu, “Solution for the Electrical Energy Storage Systems in Ship Power Systems”, *Electrotehnica, Electronica, Automatica* (*EEA*), vol. 72, no. 3, pp. 26-34, 2024

[13] M. Preda, G. Samoilescu, *Possibilities of Installing Cyclonic Flow Wind Turbines and Wind Collectors on Board Ships*, Sea Conf 2022, Constanta, 2022

[14] *** Design code - assessment of wind action on structures - 1-1-4/2012

 Digital Object Identifier 10.32754/JMT.2026.1.18