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THE POSSIBILITIES OF FISHING CUTTER ENERGETIC EFFICIENCY IMPROVEMENT THROUGH THE APPLICATION OF THE RENEWABLE ENERGY SOURCES

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Abstract

Both the limitations in the worldwide resources of the natural fuels and the requirements in respect of the environment protection growing stricter with time have caused in the recent years an interest in the non-conventional energy sources, also in the power systems of the fishing boats and cutters. The article presents the analysis of the possibilities of the application of the renewable energy sources on this watercraft. Amongst the numerous various sources only such have been taken into consideration which have the potential for the application on the fishing cutters, in varying extent for the propulsion purposes or for the auxiliary purposes, thus the wind and solar energy.

Key words: *environment protection, renewable energy sources, power system, fishing cutters*

1. Introduction

The renewable energy sources comprise the three primary sources, ie the solar, geothermal and gravity energy. Some as for instance the solar energy can be applied directly to generate heat or electric energy while the others only upon the natural conversion, eg wind or biomass or through the conversion initiated and conducted by people in various installations.

One of the physical properties of the renewable energy is its small density in comparison with the conventional energy, because for instance the solar radiation is characterised by the density <1.33 kW/m^2 and the wind by the density <3 kW/m^2 [1]. This property of the renewable energy renders hard its application on fishing cutters having the limited surface area. Nevertheless the technological progress taking place within the application technology of the renewable energy on land, and also more and more frequently on ships, provides the incentive to analyse the possibilities of its application also on smaller watercraft such as fishing cutters or fishing boats.

Under the guidance of own experience and the professional references within the application of the renewable energy sources on board the ships, it has been assumed that the same sources could be well applied on the fishing cutters and fishing boats [2, 3, 4, 5, 6, 7]. Thus two renewable energy sources have been adopted for the consideration, ie the wind power and solar energy. On account of the significantly smaller dimensions of the fishing cutters and the fact of not applying thereon the steam-powered plants it has been deemed aimless to apply solid biomass as a fuel to be burnt in boiler. Nevertheless it is worthwhile to note here the possibility of application of the liquid biomass, so eg bio-oils or alcohol for the classic Diesel engines used on cutters. In such situation

in terms of the power system arrangement and its energetic efficiency there are practically no differences in comparison with the power system utilising the Diesel oil. The only difference would possibly be the fuel heater necessary for the operation during the wintertime, on account of the higher viscosity of this fuel than in case of the Diesel oil. Another possibility would be to apply biomass in the volatile form so biogas. The main component of biogas is methane, thus the solution of the power system of a cutter utilising this fuel is more or less the same as in case of natural gas as a fuel. In such case the application of the renewable energy source practically does improve the energetic efficiency either.
The energetic efficiency of the fishing cutter power system is not always however the objective ration indicating or proving the energy consumption of the fishing process and the degree of the environment pollution with the exhaust gas emissions. Therefore it is purposeful to apply the energetic efficiency ratio including these two aspects thus the application of the renewable energy sources causing the decrease of the CO_2 emission.

2. Fishing Cutter Energetic Efficiency Ratios

The fishing cutter energetic efficiency ratio could be defined as the primary energy consumption per one tonne of the caught fish, ie:

$$\varepsilon = \frac{GW_d}{3600M} \tag{1}$$

where:
G – hourly consumption of primary fuel, kg/h,
W_d – fuel calorific value, kJ/kg,
M – weight of the caught fish, Mg.

It is worthwhile to note the universality of the aforesaid ratio, because it is independent of the kind of the fuel applied and moreover it provides for the application of the renewable energy sources. If this is biomass, then since this is not a primary fuel, the value of the ration shall be equal to zero. The similar situation will be with any other renewable energy source utilised as the sole energy source on the cutter. The simultaneous application of the primary fuel and eg the wind power or solar energy will cause the fuel consumption reduction thus the also the ratio decrease.

The disadvantage of the ratio proposed is however the dependence of its value from the length of the route covered by the cutter onto the fishing grounds and back. The further the fishing area is from the port, the worse the ratio becomes. Therefore it would seem justified for instance to apply this ratio only during the operations at the fishing area or for a longer period of operation, eg a year. For the purpose of the evaluation of the voyage to the fishing area and back to the port with the caught fish the ratios could be proposed such as for the transport ship which have been elaborated by International Maritime Organisation (IMO).
Presently all the newbuildings exceeding 400 GRT must have the determined Energy Efficiency Design Index – EEDI [8]. Moreover, there has been implemented the voluntarily determined Energy Efficiency Operational Indicator – EEOI that allows the current evaluation of the ship's transport efficiency. EEOI is defined as

$$EEOI = \frac{\sum_j FC_j C_{Fj}}{m_{cargo} D} \tag{2}$$

where:
FC_j – mass of the fuel consumed during the voyage (at sea and in port) by the main and auxiliary engines and incinerator,
J – fuel kind,

C_{Fj} – conversion factor expressed by the ratio of CO_2 mass from burning the consumed fuel of *j* kind,

m_{cargo} – mass of cargo carried (tonnes) or the work performed (number of containers TEU or passengers) or capacity (GT) for passenger ships,

D – distance in nautical miles over which the cargo was carried or the transport operation was done [9].

The value of the conversion factor C_F depend on the coal content in fuel. For instance for the Diesel oil $C_F = 3.206$ [t_{CO2}/t_{fuel}] and for LNG $C_F = 2.75$ [t_{CO2}/t_{fuel}] [9]. This is inter alia why LNG is so strongly promoted fuel for the ships in EU. Reaching the small value of EEOI is possible chiefly through any activities favouring the reduction of the fuel consumption by ships, also in port. The basic actions to reduce EEOI while at sea comprise eg the speed reduction, utilisation of the exhaust gas waste heat but also the application of the wind or solar energy.

The aforesaid regulations do not apply to the fishing cutters yet, also in view of the vessel size. However, for the purposes of the analysis, in terms of the evaluation of the fishing cutter energy efficiency and the reduction of the negative impact on the water ecosystems, the voluntary application of the EEOI indicator is justified.

Assuming the EEOI indicator for the evaluation of the fishing cutter energy efficiency in the relation (2) the caught fish mass *M* should be put in place of the carried mass of cargo m_{cargo}. It would be also reasonable to alternatively determine the indicator in consideration of the fuel consumption not only during the fish transport to the port, but also during the operations on the fishing grounds (changing the position, trawling). EEOI indicator presented by means of the relation (2) can be determined for one voyage or for the specified ship's operation time or also for the specified number of voyages [9]. Similar propositions could be suggested for such determination of the EEOI indicator in respect of the fishing cutters.

3. The Application of the Wind Power on Fishing Cutter

The general characteristics of wind in terms of the possibilities of utilising its energy on a ship has been presented in the earlier works by this author, inter alia [7]. In case of the fishing cutters the utilisation of the wind energy is brought down to three solutions in practice: the application of the sail propulsion unit, "towing kite" unit or the wind turbine for the propulsion of the electric current generator.

3.1 Sail Propulsion

Until the piston type steam engine has been invented the sail propulsion, next to the rowing oars, has been the primary and basic propulsion source utilised on boats and fishing cutters. On the fishing boats for the long time there has been applied the square kind of sail so called lug sail [10]. The sails have been used on fishing cutters for many years and even long after the piston type Diesel engine has become the universally used propulsion source. They have been acting on these ships as the auxiliary propulsion unit. The example of such vessels are inter alia the fishing cutters built in Polish shipyards after the WWII. The figure 1 shows the silhouette of the very popular fishing cutter Meyerform 17 afterwards referred to as B368 built after the war in Gdańsk Shipyard [11]. She had the sails of the ketch of the area 33 m^2. Similar type of sails with the surface area the Storem 4B (KS-17) cutters have had which were built within 1958-1961 in Stocznia Szczecińska, and later, ie since 1961 until 1970, in Szczecińska Stocznia Remontowa [Szczecin Repair Shipyard]. This type of sails/rigging has also been applied on the other vessels such as eg K15 or KS-177. A certain exception is KU-134 which had gaff sails of slup type.

The increase in the power output and efficiency of the Diesel engines, relatively low fuel prices as well as the troublesome operation and the restrictions caused by the basic fault of the sail

propulsion which is the necessity of tacking in case of the unfavourable wind direction made the sails disappear from the fishing cutters.
In view of the new circumstances, imposing upon the shipowners the necessity to improve the energetic efficiency, advisable also in reference to the cutters, this is the author's opinion that the consideration of the return to the sails becomes a necessity. The sail propulsion should be computer-aided and fully automated in operation . The utilisation of such sails with the favourable wind, at least only the passage over to the fishery or back, even, owing to the scarce surface area, acting only as an auxiliary propulsion unit, may provide substantial economic benefits resulting from the savings on some amounts of fuels and the ecological benefits ensuing from the smaller CO_2 emission.

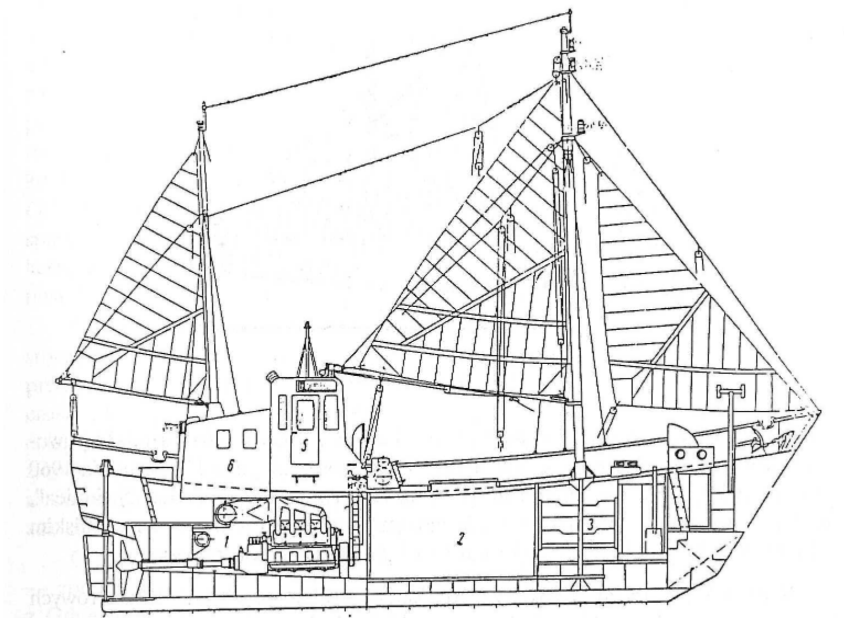

Fig. 1. Ketch sails/rigging on B368 cutter

3.2 Towing Kite

The modern overhead propeller consists a kite connected with the ship by means of a 100 – 500 m long rope which constructionwise resembles a paraglide. This arrangement utilises the bigger wind velocities occurring at the heights within 100 and 500 m above sea level. The application of the kite currently is reduced only to its utilisation as the ship's auxiliary propulsion system [7].
These solutions have already been applied on large sea-going vessels, but can also be adapted for the smaller ship's such as fishing cutters. The towing kite forms an attractive propulsion unit because the force with which it acts directly at the ship generates the towing capacity without any additional energy losses resulting from its conversion. Assuming the average value of the propulsion efficiency of the motor ship defined according to [12] as the ratio of the towing force to the power carried to the propeller shaft tail-end, equal to ca 0.5, then the equivalent engine power output must be twice as big as the towing kite power in order to give the same speed to the ship. The diagram of the forces acting on the cutter is shown in the figure 2 [13].
Although the application of the towing kite does not only depend on the full wind, but also beam wind and even one fourth of the wind power, then similarly as in case of the sail propulsion also in

case of the towing kite propulsion there is one basic deficiency, ie the necessity of tacking about in case of unfavourable wind direction.

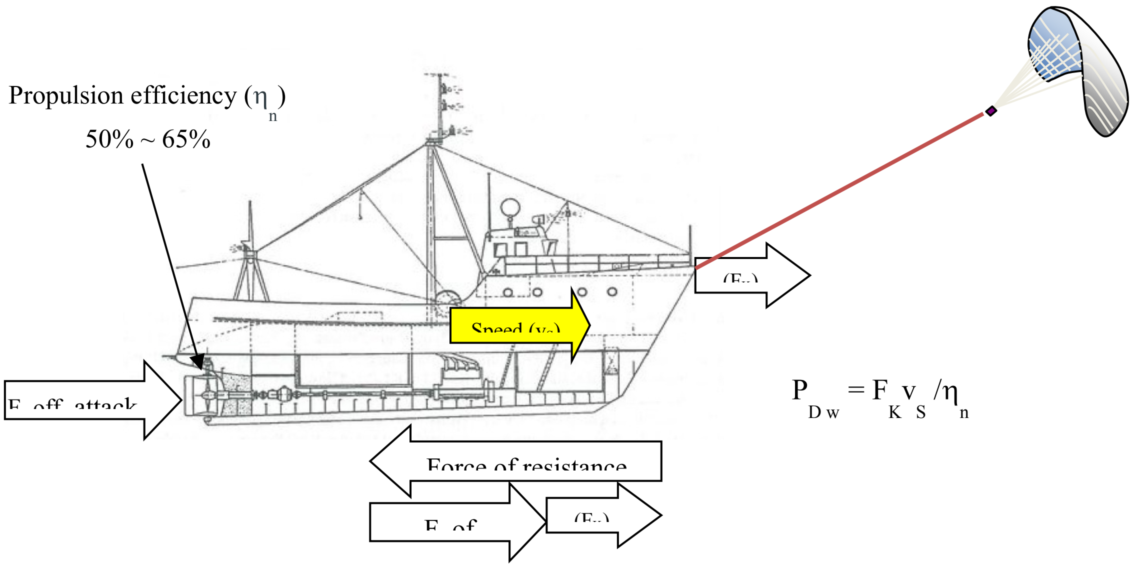

Fig. 2. The forces acting on the cutter and wind towing power P_{dw}

3.3 Wind Turbine as the Propulsion for the Power Generator

As the wind turbine power output grows along with the square of the rotor diameter, the tendency should be to apply the biggest diameters possible [7]. However, on fishing cutter the rotor diameter size must be limited on account of the small size of the vessel and the possibility of affecting the stability. In order to determine the possible power output the calculations have been made for three different possible rotor diameters, ie 0.5m, 1 m and 1.8 m. The graph showing the relation of the turbine power output and the wind speed for the assumed diameters is presented in figure 3. As evident from the graph the power values obtained are not big. With the wind force corresponding to 6 to 7 in Beaufort scale (ca 16 m/s) the power approximately 3 kW can be obtained from the turbine with the biggest diameter, ie 1.8 m. With the rotor diameter of 1 m it would be 1 kW and in case of the smallest turbine just ca 300 W.

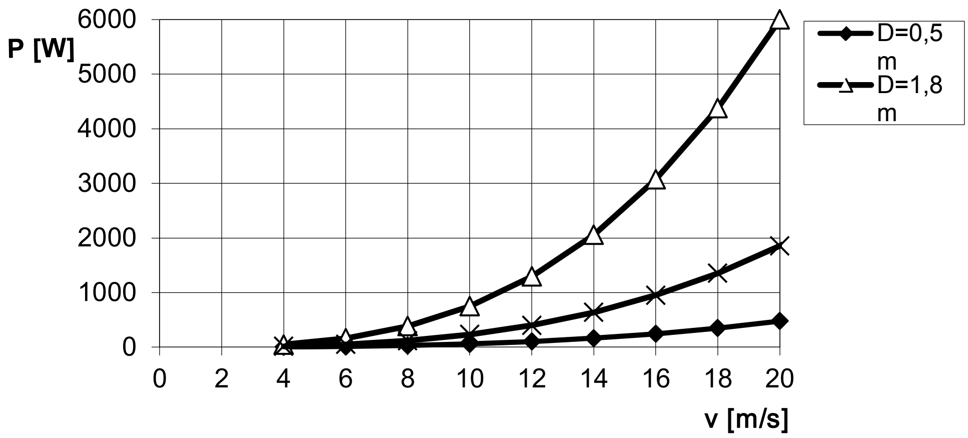

Fig. 3. The power outputs of the wind turbine dedicated for cutter for different rotor diameters in the function of the wind velocity

Currently on the market there are available numerous wind power generators dedicated for the sea-going yachts and the small inland boats. These are chiefly the turbines with horizontal rotation axis rotors [commonly referred to as the horizontal axis wind turbines HAWT] fitted with 3 blades. These are lightweight structures and resistant to sea environment. The diameters of the wind turbogenerators intended for yachts are within ca 0.5 m up to ca 2 m. Therefore from just this range the diameter values have been adopted for the aforesaid calculations. These turbines also perform excellent on fishing cutters and fishing boats.

The table 1 shows the annual theoretical amount of generated electric power subject to the wind velocity and fuel amounts possible to save by cutter under assumption of the fuel consumption by the cutter engine in the amount of 0.240 kg/kWh in respect of turbine with rotor diameter of 1.8 m (Zephyr) [13].

Tab. 1. Annual production of electric power by Airdolphin Mark-Zero/Pro and the fuel amounts likely to be economised on the cutter

Average annual wind velocity [m/s]	3	4	5	6	7	8
Annual electric power generated [kWh]	260	660	1260	2050	2970	3930
The amount of fuel saved [kg]	62	158	302	492	713	943

The offer of the wind turbine manufacturers dedicated for the smaller watercraft covers also the vertical axis wind turbines [VAWT]. An example of vertical axis design is the turbine with the Savonius rotor of Maglev System CXF-400 type developing the 400 W power with the 12 m/s wind speed. The rotor diameter is 1.2 m and its weight is 30 kg [14]. The parameters of such turbines are not that promising as those of horizontal axis design turbines. First of all they are heavier, larger and more expensive. Nevertheless they are the object of the further investigations inter alia in terms of their application on fishing cutters due to the advantage which is the low wind velocity with which they initiate, ie ca 1 m/s. The research has shown that eg with the 12 V batteries they are efficiently charged even with the small wind speed. If the charging current from the wind generator is sufficient at the time of sailing during the day, night or during the standstill, then it is possible to reduce the charging current from the engine driven generator which transposes onto the reduction of the fuel consumption.

From the foregoing analyses it can be seen that the application of the wind power generators on fishing cutters can produce concrete savings in the amounts of the fuel consumed in the annual perspective.

4. The Application of the Solar Energy on the Fishing Cutter

In practice the solar radiation energy is most often converted into heat (photothermal conversion) or into the electric energy (photo-voltaic conversion). On large watercraft as for the time being the photo-voltaic conversion has been applied. In case of fishing cutters characterised by small share of heat in the general power balance, in comparison with the large ocean-going vessels, application of only photo-voltaic conversion is most justified.

Since a single photo-voltaic cell (PV) has low voltage, insufficient to supply directly the electric power consumers, it is necessary to connect many cells. As an example connecting in a series 36 cells (typical module) made of crystalline silicone allows to obtain the voltage within 15-16 V – sufficient to charge 12 V lead-acid batteries [15]. The module means most frequently the smallest set of interconnected photo-voltaic cells complete with the mechanical construction protecting from the external conditions. The modules are also connected to form bigger elements referred to as the photo-voltaic panels. In most occasions they have the dimensions approximately 1600x900 mm. From such surface the peak energy to be obtained approximates 240 W. The solar cells are hermetically closed, thus resistant to the weather conditions which allows their manufacturers to issue long-term guarantees (often ca 25 year). The market prices of the cells recently remain below 1 €/W (average ca 0.8 – 0.9 €/W).

There are many small boats and yachts in operation worldwide which utilise the photo-voltaic cells to supply the propulsion system with electric motor or just to charge the batteries. The common feature of these vessels are their minor dimensions, operation in the absence of rolling and small sailing speed which is associated with the insignificant demand for the propulsion power. On sea-going yachts the photo-voltaic cells have been used to charge batteries. They often co-work with the wind turbogenerator. The flexible panels are particularly worth mentioning as they can be attached to the even and level surfaces of the superstructure or deck, eg by gluing.

Although the fishing cutters are not any big vessels, then the required main propulsion power output values are so big that the application of PV cells dedicated to generate the electric power to fully cover the propulsion system power demand is not realistic. The small dimensions of cutters, their construction as well as their specific tasks make the arrangement of the PV cells on board of these vessels harder than on small cruising ships or yachts.

On the other hand it is justified to utilise the PV cells on the fishing cutters for the purpose of charging batteries. The photo-voltaic panels which are used on yachts have been checked in marine conditions and are excellent choice for the installation on fishing cutters. However, it should be considered that the photo-voltaic cells are more exposed to mechanical damages on the cutters. Therefore the PV cells should be positioned in such way that the fishing operations are carried out without exposing them to mechanical damage. Namely, care should be taken so that the module cannot get into collision with boom, metal rigging elements such as eg shackle or fishing equipment. They are likely to break the board and thus cause the irreparable module destruction. In practice this means the limitation of the surface available for the installation of the photo-voltaic panels. The PV cell location should ensure the best possible exposure to sunlight, therefore little shadow. Often on account of the PV cell capacity it is better to apply several smaller modules in numerous locations instead of one big unit. On cutters, owing to the aforesaid limitations, this becomes of particular importance.

The most advantageous place to locate the cells on fishing cutter is the superstructure roof/top and possibly partially also its side walls. Another attractive place in terms of the surface area available are the hold hatch covers, but on the other hand this is a location where the cells are very likely to get damaged. For instance for the cutter of type Storem 7 (fig 4) of 20.67 m length overall and beam of 5.59 m the area estimated as available for the PV modules on the superstructure is ca 10 m^2, and including the hatch cover this is ca 12.5 m^2.

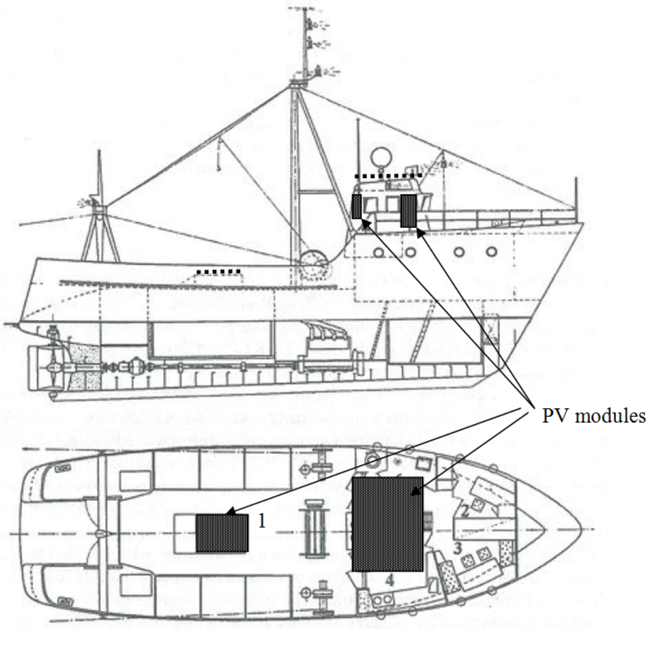

Fig. 4. The prototype Storem 7 cutter and the proposed PV module installation locations [16]

The reinforced panels, eg SOL-FL HD model made by GTB-SOLARIS, can be mounted on the hatch cover. The boards in these cells are laminate-coated, mounted on white, flexible plastic board which acts as the carrying element. Additionally the panel is reinforced by means of the aluminium sheet that protects the panels against the dents (caused by the uneven substrate). It makes them partially resistant to the indentations resulting from walking on the panels under which there is uneven surface. Because the cells are flexible they can be mounted also on a curved surface.

Assuming on the basis of the cell manufacturer's data that on the superstructure according to the STC [standard test conditions] from 1 m^2 (at the temperature of 25°C with the radiation of 1000 W/m^2) the maximum power output to be obtained is 150 W and from panels on the hatch cover 130 W, then maximum to be obtained jointly is ca 1800 W. These are values of peak power but it is worthwhile to note that they significantly exceed those obtained by the wind generators analysed earlier.

In order to determine the electric energy actually accumulated owing to the installed PV cells one should take into consideration the actual radiation value and time of sun operation within specified time (usually within a year). An often used indicator for the electric energy generation is that representing the ratio of the generated electric energy in relation to 1 W of peak power (frequently this unit is referred to as W_p). The value of this ratio will not be constant because the sunlight exposure conditions may vary in different years. The differences are generally not big and basing on such data the annual gains of electric energy can be estimated which allow to determine the amounts of fuel saved on a fishing cutter. The table 2 shows such data for CIS type cell (with the absorber containing $Cu(In,Ga)Se_2$) [28].

Tab. 2. Energy generated by the stationary module within 2000-2003 [15]

Year	Radiation on module surface, Wh/m^2	Energy generated per $1W_p$ for the stationary module in STC, Wh/W_p
2000	904 342	734
2001	976 125	767
2002	1 002 156	811
2003	934 826	764

Thus on the average it can be assumed that the module generates ca 770 Wh/W_p per year. If this value is adopted for the modules proposed in the foregoing example of the cutter with the cells for which the peak power has been estimated as 1800 W, this means a possibility of generating annually 1386 kWh. This is a value of a level obtainable by one of the most efficient 2 wind turbines Airdolphin Mark-Zero/Pro with the wind velocity ca 5-6 m/s (table 1). Therefore the savings in fuel consumption will be similar and amount to ca 400 kg per year under assumption that the specific fuel consumption of the engine would be the same.

The data shown in table 2 refer to the cells produced more than 10 years ago. Presently the ratio of electric energy generation as stated by some manufacturers such as eg REC SOLAR for the cell Solar 260PE is at the level as high as even 1150 Wh/W_p [17]. In case of the application of the panels with such cells it would be possible to obtain even 2070 kWh electric energy per year which corresponds to the savings of ca 500 kg fuel annually.

5. Summary

It is hard to explicitly state which of the presented solutions related with the utilisation of the wind and solar energy should be considered in the first place. This depends to a large extent on the financial possibilities of the ship owners. The analyses show that the market offer is abundant in the wind turbogenerators and photo-voltaic modules differing largely in prices.

This would be worthwhile to pay attention to the possibility of hybridisation of the power systems where there can be simultaneously wind turbogenerators, solar modules as well as sails. The hybrid system where besides the Diesel engine there is the electric motor acting also as the generator, supplied from the batteries charged from the photo-voltaic cell, wind turbogenerator or from the land is shown in figure 5.

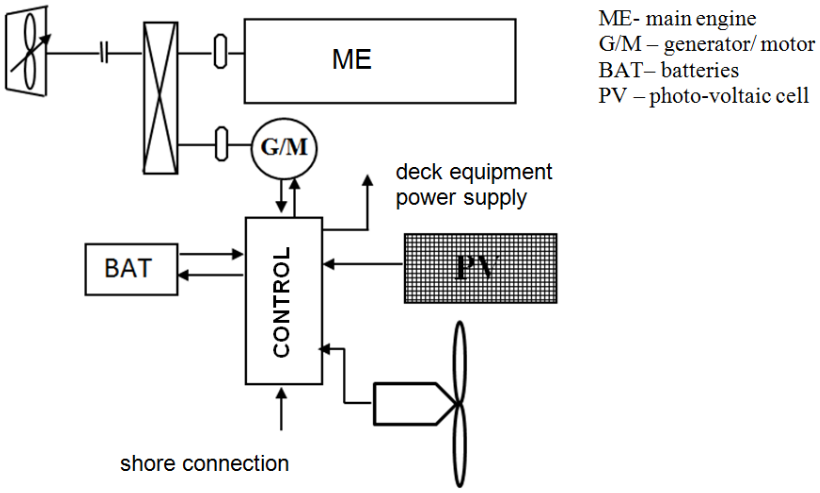

Fig. 5. Hybrid power system of a cutter including the photo-voltaic cell and wind turbogenerator

Charging the batteries is also possible by Diesel engine when the electric machinery acts as generator. The propeller can be driven by Diesel engine only, or only by electric motor or by both engine and motor together. The operation of the cutter with the utilisation of the electric motor only apart from the emission reduction has also such merit that the power system does not emit noise.

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