An Investigation into the use of Solar Sail on Catamaran Fishing Vessel

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Abstract
The attractiveness and successful application of catamaran form for passenger's vessels had inspired the naval architect to use it as fishing vessels. The investigation was carried out both experimentally and numerically. Optimum geometry or ship hull is LWL=14.5m, B=7.118 m, H=1.44 m, T=0.694 m, Displacement=11.8 ton, selected from previous work. It is then followed by model testing and evaluation for the selection of power combinations. The current work describes the development of hybrid technology for a catamaran fishing vessel using solar-sail. The models were tested at speed equal to the real vessel's speed at open sea from about 9.813 knots, and the Froude numbers were about 0.423 obtained resistance value about 6,138kN and giving the effective power (PE) about 60 kW and 6.685kN Thrust. Finally, discovered the combination of solar-sails had reached the optimum benefit of the hybrid concept of zero emissions.

Keywords—*Fishing vessel, Solar-sail power, Wind Energy, Solar Energy, Efficiency*.

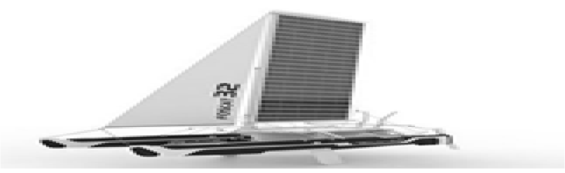
I. INTRODUCTION

The development of environmentally friendly vessels has become a major issue for the last 10 years. Without using engine and fuel oil, the powering vessel has become more popular considering issues known as a green economy concept,[1].

Several power systems choices such as sail, solar-powered boat, wave power mechanism, and the combination of those two and three power systems[2].

Despite the results of those developments are still far from economic benefits, research and development of those power systems have been carried out very intensive worldwide, such as to conduct by [3,4].

For example, in the Foscat32 catamaran tourism boat, a hybrid drive concept combines sail, diesel



motors, and solar panels [5].

FIGURE 1.Foscat32 catamaran tourism boathybrid

FIG 1.It shows the configuration of the Foscat32 catamaran tour boat equipped with hybrid propulsion which, in this case, the sail and solar panel are fitted on vertically above the ship's navigation space as the sail whose placement is adjusted according to stability, load space requirements, vessel operations and energy requirements to drive the ship. Foscat32 (Folding Solar Catamaran) is a folding sailboat utilizing natural energy from wind and sun. It has a length of 32 meters and a height of 52 meters with a solar panel (95 m^2) placed on the main pole and has two electric motors placed on the hull. This ship had high performance because it uses a lightweight system, a combination of the sun and wind power, by reducing CO2 to almost zero during sailing.

This is a reason to reduce the spread of toxic gases to the atmosphere such as CO, CO2, SO2 and NO_2,mainly caused by usingfossil fuels [6].

Similar achievements may be applied to the development of fishing vessels, and if it is successful, it can help thousands of fisherssurvive and reduce greenhouse gas (GHG).

The goal of operating a fishing vessel is to catch from the ocean that fulfills the mission's target and delivers the fish to land or another vessel for further processing. It is currently apparent that fishing vessels' catch has supplied the needs of daily food and sustains food security for millions of people in the world [7].

However, the activities have a serious impact on the increase of air pollution levels (particularly CO_2) inthe atmosphere because those fishing boats mainly using diesel engines and consuming fossil fuels. The impact of the activities is one of the most crucial problems in the world. Thus many efforts have been done to look for solutions that the operation of fishing vessels became environmentally friendly.

In general, the operation of a fishing boat is always associated with both issues. The economic factor mainly includes the cost of fuel, while the environmental factor relates to the ship's level of pollution. Economic problems and strong environmental pressures have forced ship designers and owners to create more efficient vessels to minimize diesel engines' use as ship propulsion. Reducing the magnitude of ship propulsion (and fuel consumption) can be fulfilled since the ship design stage by creating more efficient hull design and propulsion systems and ship operational activities or operations. One of them is the use of solar-sail vessels (SSV).

An example of the concept is shown in Figure 2, whichconfigures a ship with the solar-sail driver. The concept of energy conversion in the ship's configuration is to changesolar (sun) and wind energy into the ship's required thrust force through the propeller and sail. The thrust force (*T*) generated by twoor more of the ship's propulsion sources is operated together and popularly known as the hybrid system.

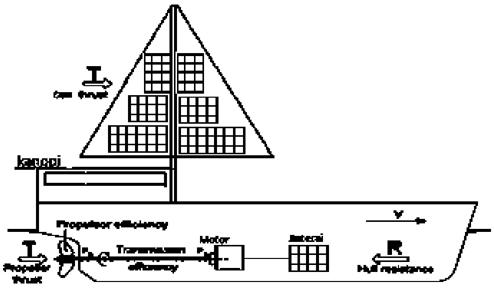


FIGURE 2. Configuration of Solar-sail Vessels (SSV)

FIG 2.It shows the configuration of the vessel with the solar-sail driver. The concept of energy conversion in the ship's configuration is to change wind and solar energy into the ship's required thrust force through the propeller (electric motor) and sail. The Thrust (*T*) force generated from one or more of the ship's propulsion sources operates simultaneously or together, knows as the hybrid system.

II. LITERATURE REVIEWS

A. Ship Moving Theory

The vessel may move forward due to a sufficient thrust to barrier ship resistance at a particular servicespeed [8]. Based on the above concept, the requirements of the ship can move.

$$T \geq R_T \quad or \quad T - R_T \geq 0 \quad (1)$$

where: T is Thrust (kN), R_T is Resistance (kN)

B. Ship Resistance

The vessel resistance (R_T) is calculated according to Equation (2),whereissaltwater density(ρ),Coeff.ofresistance(C_T), wettedsurfaceareas(*WSA*),andVsis servicespeedofship, [8].

$$R_T = \frac{1}{2} \rho \, C_T \, (WSA) \, V^2 \quad (2)$$

C. Thrust

Thrust (*T*) is the energy or force required to drive the vessel and can be expressed in Eq. (3), [8].

$$\text{Thrust } (T) = R_T/(1-t) \quad (3)$$

where: t is thrust deduction factor

For double screw [3]: $t = k_R \cdot wt$ (4)

where: $k_R$is 0.5 for the thin rudder.

$$wt = -0.0458 + 0.3745CB^2 + 0.1590Dw - 0.8635Fr + 1.4773Fr^2$$

$$D_w = \frac{B}{\nabla^{1/3}} \sqrt{\frac{\nabla^{1/3}}{D}}$$

To move, the thrust (*T*) force generated through the propeller and the sail must be greater than the existing total vessel resistance (R_T), mathematically expressed in (6).

$$T = T_{Propeller} + T_{Sail} \quad (5)$$

$$T = T_{Propeller} + T_{Sail} \geq R_T \quad (6)$$

$$\text{Propeller thrust, } T_{Propeller} = K_T \cdot \rho . n^2 . D^4 \quad (7)$$

where: thrustcoefficient *(K_T)*, Salt water density *(ρ)*, propeller rpm *(n)*, propeller diameter *(D)*

$$\text{Sail thrust, } T_{Sail} = q \cdot As \quad (8)$$

where: Dynamic wind press $(q) = ½ \text{ x } \rho \text{ x } £ \text{ x } V_w^{\ 2}$ (ton/m^2), Air mass density (ρ) = γ/g, Weight per unit volume (γ) = 1.2265 t/m^3, g = 9.81ms^{-2}, £ = wind pressure coef. (1.1), wind speed (V_w), sail area (*As*).

D. Powering

Engine conventional is the vessel's prime mover, which works by converting the fuel energy to rotate the blades, thereby producing sufficient Thrust to drag ship resistance at certain service speeds. One of the most fundamental methods of power-sharing in this conventional driving force is to distinguish between the effective power (*PE*) required to drive the ship and power delivered (*PD*) on the ship propulsion unit [8].

The formulations used are as follows:

$$\text{Effective power (PE)} = R_T \text{ x Vs} \quad (9)$$

$$\text{Delivered power (PD)} = PE / \eta D \quad (10)$$

Quasi propulsive coefficient

$$(\eta D) = \eta P . \eta H . \eta R$$

(11)Service power $(Ps) = PD / \eta T$ (12)

where: ηT is 0.98 with a gearbox, 0.95 without a gearbox. Installed power $(PI) = Ps + Margin$ (13)

Margins (*roughness*, *fouling, weather*) 15 – 20% depending ona shipping route.

Solar cells, or photovoltaic (PV), is a technology system that converts sunlight into electrical energy through solar panels stored in batteries[9]. The formulations used are:

$$\text{Power requiremen t}: P = V \text{ x } I \quad (14)$$

$$Pmax = Voc \text{ x } Isc \text{ x } FF \quad (15)$$

$$\text{Fill Factor}: FF = \frac{V_{mp} \text{ x } I_{mp}}{V_{oc} x I_{sc}} \quad (16)$$

$$P_{Watt\,peak} = PVarea \text{ x } PSI \text{ x } \eta pv \quad (17)$$

A solar vessel's concept converted sun energy into the driving force required by vessels through solar panels, batteries, electro motors, transmissions, and propellers at a certain speed. In detail, solar panels function to capture the sun's energy and convert it into electrical energy, then stored in a battery. Power stored in the battery will be used to supply the electric motor and rotate the propeller. The vessels can move forward due to the thrust force produced by the propeller (*Tp*). Since2002,researchonthetechnologyofcombineduseof windandsunpowerintheformofaSolar-sailhasbeendevelopedintheUSA,[10].

FIGURE 3.Solar sail NASA JPLType, [10]

FIG.3 shows Solar sail NASA JPLType. This solar sail is made of thin Mylar or Kapton films with a thickness of 7.6 mm and has a broad density (defining the weight of the material divided by the area of material) of about 11 g / m^2.

The solar sail has 2 (two) functions, namely: 1) As a propeller vessel, 2) As a system of Photovoltaic technology that converts sunlight into electrical energy. An efficient combination between the sail and the solar panel is very suitable to be applied as an environmentally friendly vessel.

DeterminationofSailAreaalmostasacomparisonofsailarea(As) and WSA (wetted surface area)isbetween2.0and2.5. It's knownassailratio(SR),[11].According to [12], there is another way, where the determination of SR depends on the LWL of the ship by using the graph shown in FIG. 4.

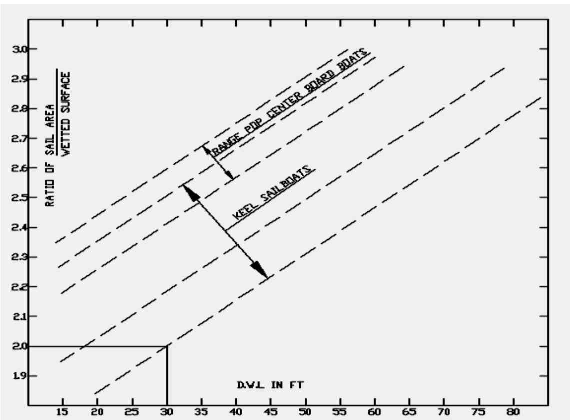


FIGURE 4. Graph of SR – LWL Relationship

FIG.7 shows a graph of the relation between SR with LWL, which can determine Sail Area with 15 - 80 feet or 5 - 25 m LWL limitation.

E. Voyage Profile

The normal voyage profile of fishing vessels according to[13], areas follows: a)The ship departs and operates in the port (Departure fromport),b). The ship goes to the location of the fishing ground(Outward bound),c).The ship arrives at the location fishing ground and fishing(Onfishingground),d). When the ship leaves the location of the fishing ground to the port(Homewardbound),e). When the ship arrives at the port and docked at the port(ArrivalatPort).

A fishing vessel must be completely safe(veryseaworthy indeed); even the ship must work in bad weather. All work on the fishing boat must be done quickly, begin from the catching until the processing of the catch is a function oftime. The slow catching causes the fish to run all(migrations), while the sluggish processing of the catch causes the fish to be damaged.

III. METHOD AND RESULT

This research is a continuing research that has been done[14]. Data's and information used there sults of previous research to support scientific/academicand its application.

FIGURE 5.Towing test of Ship Resistance

FIG. 5 Demonstrate of Catamaran Hull Resistance Model Test through experiments in the hydrodynamic Tank, while Table 1 shows the ship dimension data as the model.

TABLE 1
Dimension of Ship

Parameter	*Catamaran*	*Demihull*
LWL (m)	14.5	14.5
B (m)	7.118	1.318
H (m)	1.44	1.44
D (m)	0.694	0.694
C_B	0.434	0.434
Displ. (ton)	11.8	5.9

Test result:

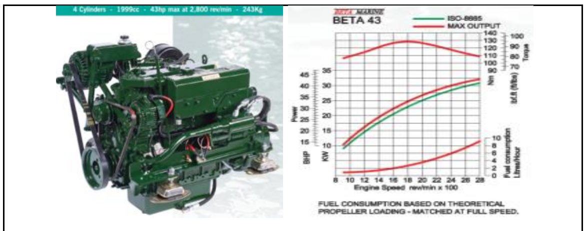
TABLE 2
Result of Resistance Test

Run No.	V (knots)	Fr	Catamaran Resistances (kN)		
			S/L=0.2	S/L=0.3	S/L=0.4
1	5.788	0.250	1.821	1.659	1.659
2	6.218	0.268	2.141	1.851	2.061
3	6.677	0.288	2.443	2.239	2.348

4	7.051	0.304	2.852	2.678	2.947
5	7.560	0.326	3.460	3.568	3.547
6	8.032	0.347	4.467	3.954	3.766
7	8.384	0.362	4.844	4.345	4.341
8	8.818	0.380	5.149	4.790	4.662
9	9.233	0.398	5.807	5.592	5.515
10	9.813	0.423	7.101	6.448	6.138

Table2 shows the experimental results of catamaran resistance into wing tanks. Furthermore, this data will be developed as a basis for designing the concept of a catamaran fishing boat with acombination of solar-sail.

Powering calculation result: Effective power (*PE*) 32,435 kW, quasi-propulsive coefficient (*ηD*) 0.664, delivered power (*PD*) 50.21 kW, transmission losses (*ηT*) 0.98 without gearbox, service power (Ps) 51.235 kW and installed power (*PI*) of 60 kW with total efficiency (*PE/PI*) is 54%. Engine used 2 x 43 hp or 2 x 30 kW. The specifications of an engine see in FIG. 6.



Type : Beta Marine
Power engine : 43 hp max at 2,800 rev/min
Fuel consumption:10 Lt /hr (at continuous Ratting)
Engine Dimension : L : 978 mm, B: 622 mm, H:740 mm, Weight : 243 Kg

FIGURE 6. Specification of BETA 43 Engine

The result of Sail Area determination: Boats with 14.5 m LWL (47.56 feet) obtained approximately 125 m^2. The calculation results of Thrust is obtained for 6.685 kN with thrust deduction factor (t) of 0.038. Propeller thrust (*Tp*) is achieved at the speed of the ship's service (*Vs*) of 9.8 knots while the thrust force (*Ts*) is reached at wind speed (*Vw*) of 19.2 knots. The results of the above calculation are then used to create *Hybrid Curve Charts* as shown in Figure 5. This curve can be used to calculate SSV efficiency.

The result of recent study is the layout of catamaran fishing vessel are presented in FIG. 7.

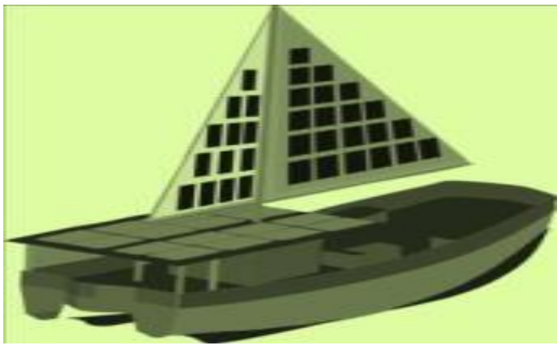


FIGURE7. Solar Sail Catamaran Fishing Vessel

The layout SSV shows the arrangement of fish holds an area for crew activities on the main deck. The wider space area for fishing activities on main deck is the primary concern for the commercial fishing industry now. The space area on main deck for catamaran is mostly related to the separation length ratio (S/L). Therefore, this ratio need to be investigated and discussed into the resistance performance to estimate the ship speed and powered required. Large areas provides an incredible amount of spaces for accommodation, engine room and massive fish storage.

The Data of SSV is LWL=14.5m, B=7.118 m, H=1.44 m, T=0.694 m, Displacement=11.8ton,LWT 7.476ton, Payload 14 GT, Power: electric motor and Sail supply by Solar Panel 170 pcs @360 WPwas placed under canopy 48 pcs (50 m^2 areas) and remaining put on sail in the form of solar sail NASA JPLType(125 m^2).

Solar panels were used to absorb energy from sun-rays and then saved into a battery. A battery recharge controller circuit managed this mechanism is presented in FIG. 6.

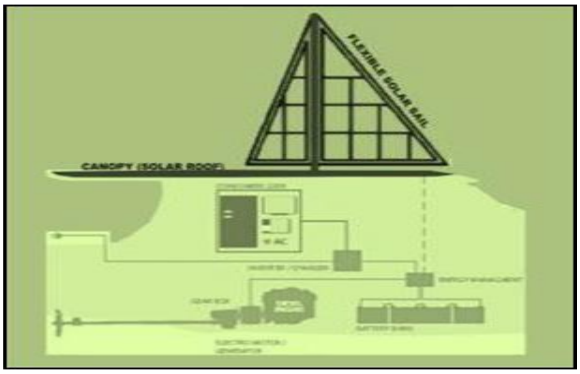


FIGURE 8.Configuration of the hybrid system.

FIG.8shows the configuration of hybrid system which can do automatic work.The controller maintains the battery voltage of about 24. If the voltage drops until22.2, then the controller will charge the battery using energy from a solar-cell panel. The controller will stop recharging process when arrives at 26.3.

III.DICUSSION

By using Equation(9), it can be determined that the magnitude of a thrust deduction factors(t) is 0.038, hence the thrust of ship(*T*) is 6.685kN, whilst the ship resistance is 6.138kN. It means that as the thrust is greater than ship resistance thus the boat will move, sea also Equation(1). As the fishing vesselis designed tousea solar-sail drive(*SSV*), the generation of thrust to move the ship comes from propeller and sail. When the ship moves, the propeller and sail can work individually/separatelyor to getherasahy brid system both with service speed(*Vs*)of9.813knots.

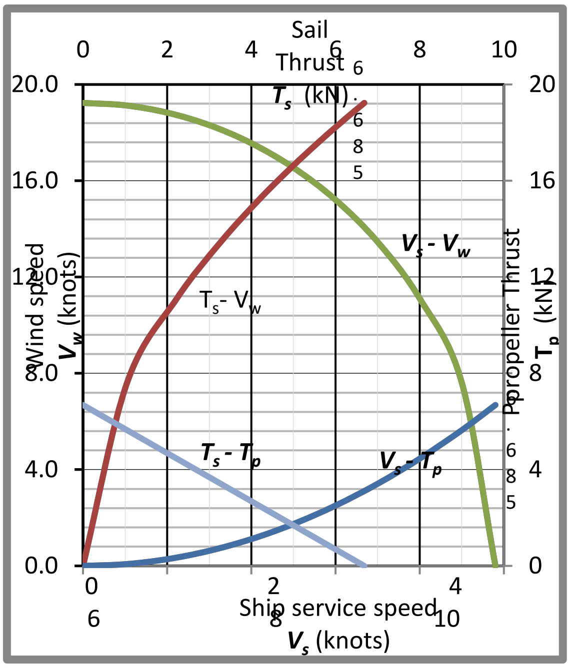


FIGURE 9. Hybrid Curve Chart, [1]

The relationship between propeller thrust (T_P), see Equation (3) and sail thrust (T_S), see Equation (7) is shown in FIG 9,T_P–$T_S$curve. Meanwhile, the relationship between wind speed (V_W) with the sail thrust (T_S) is shown in FIG. 9, the V_W–$T_S$curve. Likewise, the relationship between ship service speed (V_S) and propeller thrust (T_P) is also shown in FIG. 9, the V_S–$T_P$curve. The relationship between wind speed (V_W) and ship service speed (V_S) is called the V_W–$V_S$curve.

TABLE 3.
Details of Hybrid Curve Chart

No	Number of Axis	Relationship of
1	Axis **1**isT_sSail Thrust (kN),	T_s – T_pCurve use ordinate **1** and abscise **2**
2	Axis **2** is T_pPropeller Thrust (kN)	V_s- V_wCurve use ordinate **3** and abscise **4**
3	Axis **3**isV_sShip speed (knots)	V_s – T_pCurve use ordinate **3** and abscise **2**
4	Axis **4**isV_wWind speed (knots)	T_s- V_wCurve use ordinate **4** and abscise **4**

TABLE3 shows number of axis and relationship of Hybrid Curve Chart as shows in FIG.6. The economic value of the use of wind energy is equated with the fossil energy, then to calculate the ESVefficiency and how the hybrid systemat SV will be explained indetail in the following case study.Inorderto test the validity of the present approach as summarized in FIG9, a case study is given, namely Case Study1.

Case Study 1

When SSV is operated the sea breeze blows (V_W) with the varying speeds of 0.0, 4.0, 8.0, 12.0, 16.0, and 19.2 knots at noon (Assuming normal weather). By using *Hybrid Curve*, estimate: Thrust of sail (T_S), Thrust of propeller (T_P), contribution of propeller to T_S thus the vessel can be operated at the service speed (*Vs*) of about 9.813 knots.

Answer:

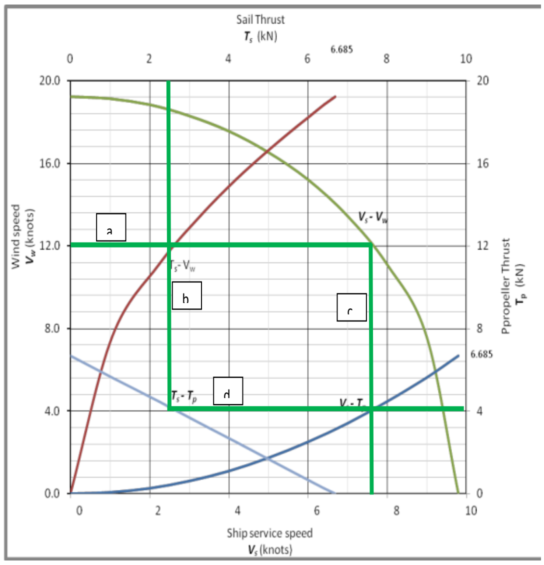


FIGURE 10. Applied of Hybrid CurveChart

TABLE 4.
The Result of Case study 1

Table 4 shows Result of Case study 1 and How the Hybrid System (SSV) work i.e.: the propeller and sail can work individually/separately or together as a

.Sail		Propeller		Prime mover
***Vw* (Knots)**	***Ts* (kN)**	***Tp* (kN)**	***Electric motor Rpm***	
0.0	0	6.685	1700	Propeller
4.0	0.5	6.185	1550	Propeller-sail
8.0	1.2	5.485	1480	Propeller-sail
12.0	2.4	4.285	1300	Propeller-sail
16.0	5.4	1.285	1000	Propeller-sail
19.2	6.685	0	0	Sail

hybrid system when the ship moves.

Service speed (Vs) on fishing boats is a major requirement because fishing vessels must arrive at the fishing ground as quickly as possible so as not to lose the right time to catch fish. This fishing vessel sailed with operational speed of around 9.8 knots. At this speed the ship will experience a drag force (*RT*) of 6,423 kN with the need for Thrust (*T*) of 6.685 kN. To meet the needs of the thrust force is supplied from propeller propulsion (*Tp*) with a 2x30 kW electric motor and sail (*Ts*) with an area (*As*) 125 m^2. The optional of service speed is adjusted to the voyage profile of the fishing vessel itself. When the ship operates in the port area (*departure from Port*) in an empty load state, the ship will use a speed of about 2 to three knots only. At this time, the use of engines and sail is highly recommended. When the ship goes to the location of the fishing ground (*outward bound*) without cargo load state and after the ship is on the high seas, it will use full service speed of 9.813 knots, because the fishing vessel must arrive at fishing ground according to the planned time (on time) by using the engine and sail simultaneously. When the ship arrives at the location of the fishing ground in an empty load state and then doing the fishing operation on the fishing ground will tend to use a speed of about 4 to seven knots because the fishing equipment set up requires a rather fast time, and if it is not quickly worried the fish will run all. At this time, the use of propeller and sail simultaneously/alternately is highly recommended depending on the situation. When the ship leaves the fishing ground location (*homeward bound*) to the Port in full load condition with the catch, fulfillment of thrust force is generated from the propeller's use and sail simultaneously to reach speed service 9.813 knots. And when the ship arrives at the Port (*arrival at Port*), the ship only uses about 2 to 3 knots by using the propeller and sail alternately. The use of wind energy to drive SSV with Vs. 9.813 knots with service speed requires a *Vw* wind speed of 19.2 knots to produce a thrust force of *T* of 6.685 kN.

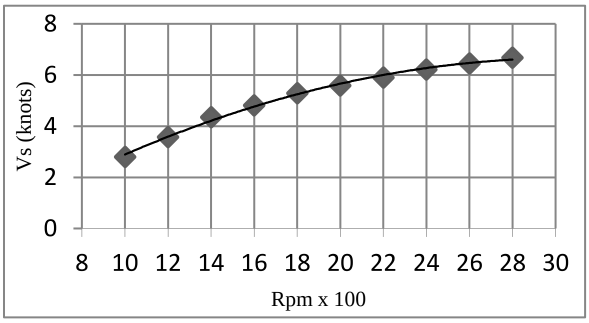


FIGURE 11.Rpm-Vs Chart.

FIG. 11.Shows relationship between Rpm-Vs Chart.

V. CONCLUSION

Application of hybrid technology use a combination Solar-Sail has potency to save fuel usage until 100%. It's very useful when applied to catamaran fishing vessels and hence reduce an emission of greenhouse gases. The present work apparently portraits of study into the development of a more energy efficient and fewer polluted fishing vessel.

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