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Design of Hybrid (PV/Gasoline) Propulsion For Small Fishing Vessel

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Abstract

The mechanism of hybrid (PV+gasoline) for fishing vessel propulsion was aimed to reduce fuel consumption. The background of this research is lots of vessels not going for fishing because of a lack of fuel. With the hybrid mechanism, the fishing vessels could less fuel consumption without decreases its performance (torsion, power durability, and velocity) when cruising. In this paper, a parallel hybrid (PV/gasoline) is proposed. The gasoline generator will deliver power to DC motor if PV energy that stored to the battery not enough as the requirement of propeller propulsion. Hybrid design for a 3-ton overall weight of fishing vessel was designed with eight-unit solar panels @200 WP arranged as four string-2 series. Li-Ion battery pack with 4.5 KWH of capacity was used as energy storage. The simulation shows that the hybrid scheme can preserve the vessel speed at 16 Km per hour with time duration in 12 hours 46 minutes and needs 4 hours 10 minutes for full battery charging by a gasoline generator.

1. Introduction

Fishers feel that the fuel consumption for fishing is abundant. Many fishers are not going fishing because of a lack of fuel supply. On the other hand, solar panel technology is widely used as alternative energy. Photovoltaic has been well implemented for a small electrical generator installed on a home or office rooftop. It was rare to using solar panels as vessel propulsion because of low power continuity and durability. Spagnolo, et al propose the concept of a solar electric boat for tourism transportation [1]. This catamaran boat was able to cruise with 15 Km/hour as long 15 hours with battery 82 kWh battery capacity. The boat concept has dimension Length Overall LOA = 14m and Wide W = 0,9m. There were 42 solar panels @ 225 WP to produce 9.45KW of power at standard conditions.

The concept of solar-powered catamaran fishing vessels was introduced by Utama et al. [2]. The result of this design is a fishing vessel with 31 tons of displacement. Two 55 KW electric motor was installed to against 18.56 KN resistance of the boat to get 10 Knot service speed. Khizir et al. [3] designed and fabricated a boat with photovoltaic propulsion. PV panels with 7.03 m2 of the area were capable of serving power of the 200 Kg epoxy boat with speed 7.4 Km per hour. Kobougias et al. [4] propose the benefit and disadvantage of the kinds of photovoltaic string configuration that implemented as boat propulsion. Design optimization for leisure catamaran passenger boat with 42 person capacity was proposed by Nasirudin, et al [5]. Thirty-two solar panels @280WP was installed as rooftop was capable of giving 16.258-ton displacement with 5-knot service speed. Battery pack with a rating at 12V 90Ah is adequate for 5 hours cruising. Refer to the studies mentioned earlier show that durability and intensity of photovoltaic power are limited for vessel propulsion.

The hybrid mechanism by combining solar energy and a fuel engine as vessel propulsion is appropriate to be used. Studies about PV hybrid for propeller-based propulsion have been introduced. Santosa et al. have conducted simulation and experimentation about the hybrid mechanism by combining diesel, sail, and solar panels [6]. The combination was able to reduce 6 liters of fuel consumption every hour cruising. Lee et al. [7] proposed the usage of hybrid PV/diesel for a green ship that operates in two modes, stand-alone and grid-connected. Solar panel with 3.2 KW power rated was combined to 20 KW diesel generator. The vessel was able to voyage smoothly, although switching between two modes was occurring by use power support from a battery bank.

Electric ship with DC motor as propulsion was modeled by Visali et al. [8]. DC motor power was supplied by diesel generator, battery power bank, fuel cell, and PV. The simulation shows that the system could increase voltage response and maintain a constant value refer to the given set point. This study discusses hybrid (PV/gasoline) propulsion for a small fishing vessel by a mathematical model, which shows the performance of the hybrid system. This research aims to find out the performances (thrust, velocity, and battery charging) of hybrid (PV/gasoline) propulsion for the small fishing vessel, further become a reference in prototype fabrication.

2. Methods

The hybrid (PV/ Gasoline) model was described by simulation. The main dimension of the vessel is shown in Table 1. Specification and power requirement calculation generally discussed on [9]. Solar panels were installed as hull rooftop, as shown in Figure 1.

Table 1. Small Fishing Vessel Main Dimension

Dimension	Notation	Value (m)
Length Overall	L_{OA}	7
Length Between Perpendicular	L_{BP}	6
Overall Wide	W	2
Height	H	1,5
Depth	D	0,9

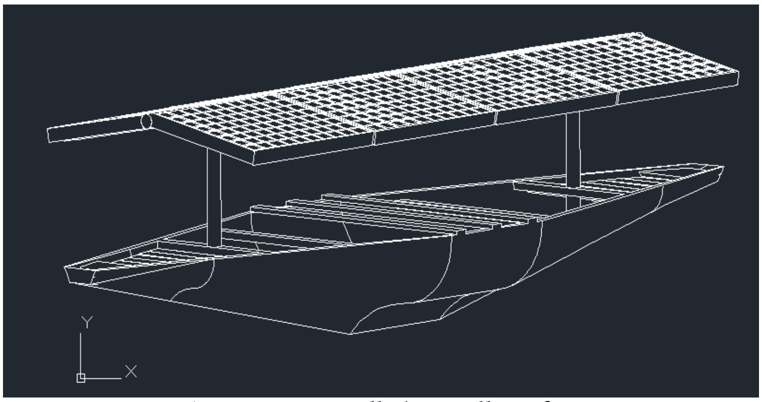

Figure 1. PV Installed as Hull Rooftop

2.1. Fishing Vessel Hull Hybrid Propulsion Model

Hybrid propulsion consists of eight solar panels @200 Watt Peak that arranged as four series-two string combined to 3 KW gasoline Genset by parallel hybrid configuration. With the arrangement, the vessel should be enough to carry 300 Kg haul of fish and two fishers. Photovoltaic energy is stored in the battery pack. MPPT (Multi-Point Power Tracking) with 90% efficiency is installed to get optimal energy absorption. The hybrid configuration is shown in Figure 2. Table 2 shows the specification devices used in the scheme.

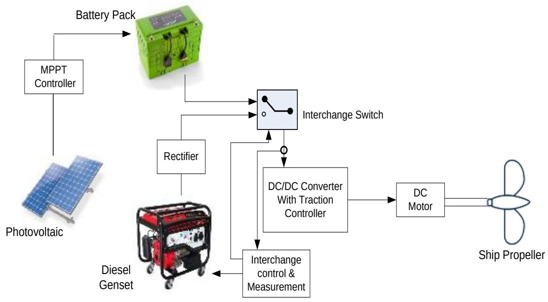

Figure 2. Hull Propulsion Hybrid Scheme

Table 2. Device and Specification of hybrid Propulsion.

Devices	Specification
Solar Panel	– Monocrystalline 200 WP – Dimension 1335 x 1007 x 85 m – Weight : 16 Kg
MPPT controller	– Current Rating: 60 A – Voltage Rating :48V – Voltage Input : 150 V (max)
Battery pack	– NCA Li-Ion

	– Voltage : 50 V – Capacity : 4.5 KWh
Genset (Gasoline)	– Output Power: 3 KW – Dimension : 615 x 465 x 445m – Weight : 38 Kg
Rectifier	– Power Rating: 3 KW – Input Voltage : 220V – Output Voltage : 51 V – Current Output : 80A
DC-DC converter	– Power Output Maks : 3 KW – Voltage Output : 0 - 51 Volt.
DC motor	– Nominal Voltage : 48 V – Maximum Power : 3 KW – Torsion : 9,1 Nm / 2800 rpm

The battery pack will supply energy for DC motor to actuate hull propeller. When battery energy just 30% remaining, the interchange controller will switch on the gasoline generator. After the generator switched on, interchange switch moves to rectifier output, then DC motor supplied by a generator. When a battery is fully charged, switch moved to use energy stored in the battery. Battery State of Charge (SOC) provided by PV and generator described as [10] is shown in Eq. 1.

$$E_{ESS(s,t)} = E_{ESS(s,t-1)} + \left(E_{Gasoline(s,t)} + E_{PV(s,t)} - E_{load(s,t)}\right)\eta_{ch} = E_{ESS(s,t-1)} + \Delta P.h.\eta_{ch} \quad (1)$$

If thrust is needed, the battery will release power (discharge) as shown in Eq. 2.

$$E_{ESS(s,t)} = E_{ESS(s,t-1)} - \left(E_{Gasoline(s,t)} + E_{PV(s,t)} - E_{load(s,t)}\right)/\eta_{ch} = E_{ESS(s,t-1)} - \Delta P.h/\eta_{ch} \quad (2)$$

with: E_{ss} : SOC (*State of Charge*) *battery* in %, E_{load} : Released energy ,E_{PV} : Energy from PV, $E_{gasoline}$: Supplied energy from gasoline and ΔP : power balance. Photovoltaic power output is written in Eq. 3.

$$P_V = \eta_{pv}.\, A_{pv}.\, G_{s,t} \quad (3)$$

With: η_{pv}: solar panel efficiency, A_{pv}: Effective area of solar panel, G : Energy generated by solar panel per m^2. A dynamic model of gasoline generator is describe in Eq. 4.

$$T_m(s) = e^{-\tau s}\frac{K_y}{1+\tau_c s}Y(s) \quad (4)$$

where T_m: output torsion K_y: torsion constant Y: fuel index related to governor setting, as shown in Eq. 5 and Eq. 6.

$$\tau \approx \frac{1}{n_m N} \quad (5)$$

$$\tau_c \approx \frac{0{,}9}{2\pi n_m} \quad (6)$$

with n_m: angular speed of engine N: number of engine cylinder . Thrust and torsion produced are described in Eq. 7 and Eq. 8.

$$T_P = \rho D_p^4 K_T n_m |n_m| \quad (7)$$

$$Q_P = \rho D_p^5 K_Q n_m |n_m| \quad (8)$$

with ρ : Sea water density, D_p : Propeller diameter, K_T : thurst coefficient, K_Q : torsion coefficient, n_m :propeller angular speed. Thrust is determined by hull resistance written as in Eq. 9.

$$T_p = {}^{R_T}/_{(1-t)}, \quad (9)$$

t is deduction coefficient of thrust with valued $0{,}12 \le t \le 0{,}30$ [11]. Hull resistance described as in Eq. 10.

$$R_T = {}^{1}/_{2}.\rho.W_{SA}.V^2.C_T \quad (10)$$

with: W_{SA} : Wetted surface area, V : Hull velocity, C_T : Total resistance coefficient. Required power (Watt) to drive propeller as described in Eq. 11.

$$E_{Watt} = R_T V \tag{11}$$

Calculations to estimate hull resistance refer to Eq. 10 are $R_T = 440{,}05\ N$, $R_{T+15\%\ margin} = 506{,}06\ N$. So total required power is $E_{Watt} = 1.685\ KW$. Therefore 3 kW gasoline engine or 8 solar panels @200WP can give thrust for the boat at 12 km/hour service speed.

2.2. Simulation

The topology in Figure 1 that is described as a simulation is shown in Figure 3. The Input system is constant ambient temperature at T=25° C dan solar radiation, which varies between 0 - 1000 W/m². The variation of solar irradiation value is shown in Figure 4. Simulation outputs are electric current generated by solar panels, SOC battery, RPM of propeller, and cruising vessel velocity.

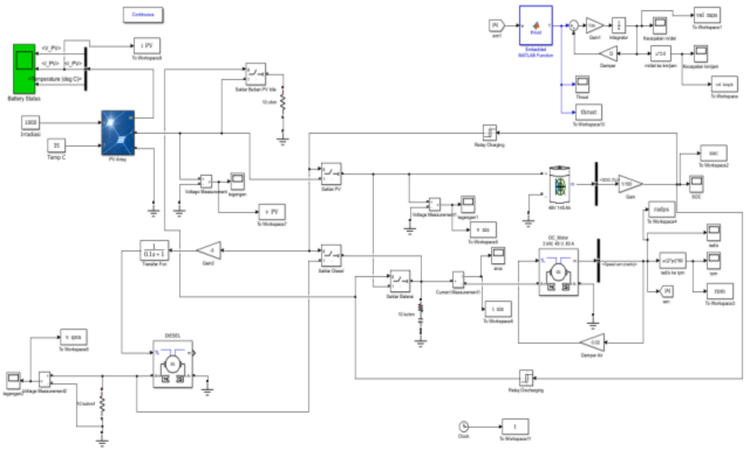

Figure 3. Simulation Diagram

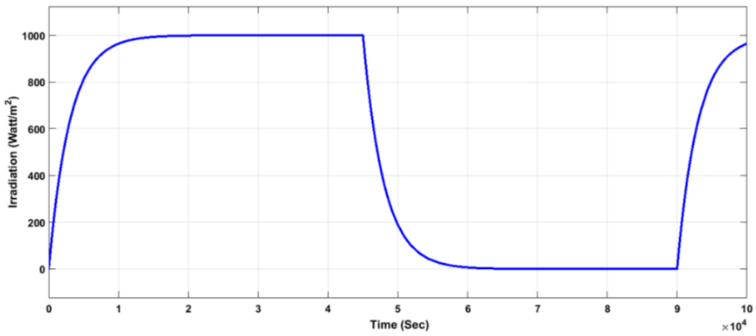

Figure 4. Solar Irradiation Input

3. Results and Discussion

The Propeller operation is followed in Eq. 7 and Eq. 8. With thrust T_P = 500N and diameter D_p = 0,25m, the propeller will optimally operate at 1200 rpm. Electric current generated by PV is shown in Figure 5. Output is DC, with amplitude 28 A when solar heat intensity is 1000 Watt/m² and null when there is not solar intensity.

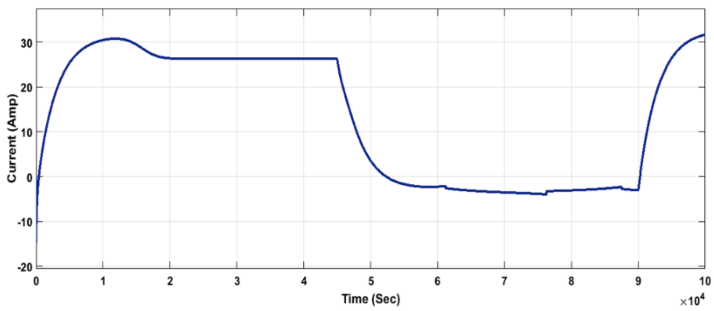

Figure 5. Current output of PV

Battery State of Charge (SOC) follow Eq. 1 and Eq. 2 shown in Figure 6.

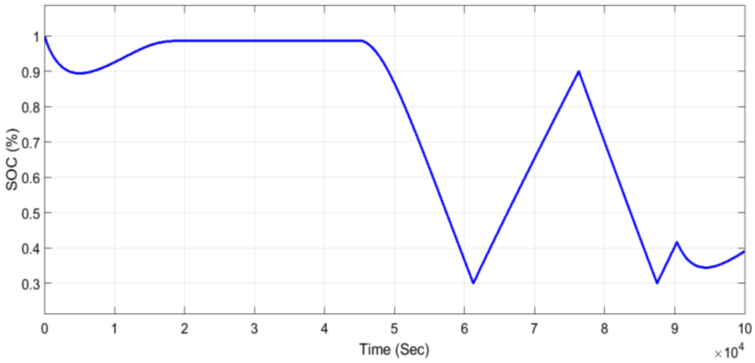

Figure 6. Battery SOC

When solar intensity is enough, battery charged by PV, and if not gasoline generator, will be switched on to charge the battery. Energy form PV can be used to cruise as long 12 Hours 46 minutes after there is no stored energy in the battery and solar intensity is low; genset will charge as long 4 hours 10 minutes to reach 100% battery SOC. Propeller angular velocity from Eq. 7 and Eq. 8 is shown in Figure 7 that shows the angular velocity sustained at n = 1200 rpm as given set point, although the transition between generator to PV occurs.

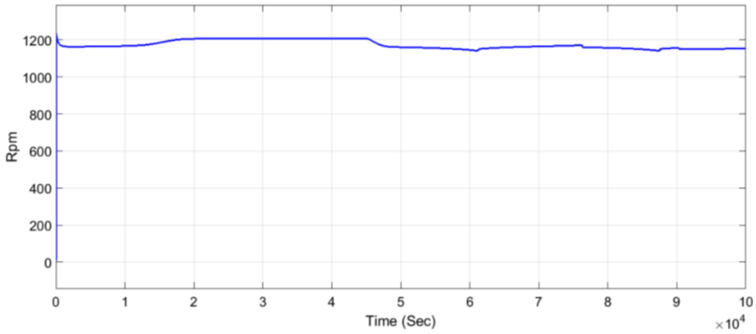

Figure 7. Propeller Angular Velocity

Hull velocity when cruising is calculated based on Eq. 12 and the response is shown in Figure 8.

$$V = \frac{2\pi Q_p n_m}{T_P} \tag{12}$$

From Figure 8, it is known that the vessel can voyage at a constant velocity as a given set point. The Thrust that required to maintain the velocity follows Eq. 9, as shown in Figure 9.

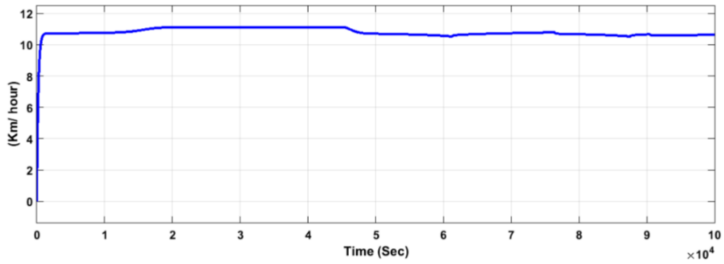

Figure 8. Vessel Velocity

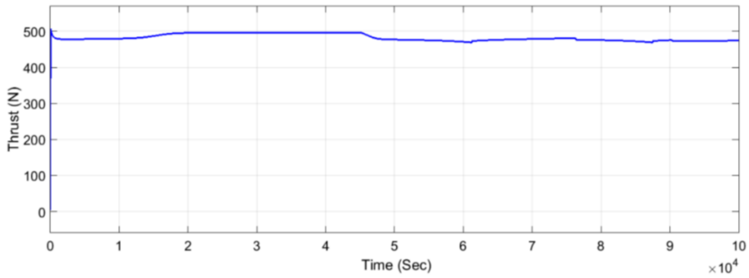

Figure 9. Thrust

4. Conclusion

The design of hybrid (PV/gasoline) propulsion for the fishing vessel was conducted by simulation. The total weight of the hull is 3 Ton with 300 Kg harvested fish and two fishers. Gasoline engine with rated 3 KW dan eight solar panels with rated @ 200 WP in 4 series-2 string configuration operates alternately depend on battery SOC. The simulation shows that with a variation of solar intensity, the vessel still able to maintain cruise at 16.5 Km/hour vigorously though the power is being switched from PV to the generator and vice versa.

Form battery SOC, it is known that battery can serve power for vessel thrust until 12.5 hours cruising. Further, it can be proposed the design of a hybrid charging station for an electric fishing solar boat, so it does not need solar panels and a generator erected on the hull to decrease its empty weight. The charging station is going to use energy from a solar panel and State Electricity Enterprise (PLN) network with PV on the network configuration so it is more environmentally friendly.

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