METEOR STIP MARUNDA

pISSN : 1979 – 4746
eISSN : 2685 - 4775

Maritime Institute of Jakarta

Utilization of Solar Cell Power Generation System to Reduce Fuel Consumption on MT. Hendropriyono III

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Submitted: 07/04/2023 ***Revised***: 19/05/2023 ***Accepted***: 25/06/2023 ***Published***: 30/06/2023

Abstract

The use of fossil fuels as the primary energy source for ship power generation has led to increasing environmental concerns, particularly regarding greenhouse gas emissions and fuel depletion. This study investigates the utilization of a solar cell power generation system as an alternative energy source to reduce fuel consumption on MT. Hendropriyono III, a tanker vessel operated by PT. Cakra Manunggal Semesta. Employing a Research and Development (R&D) methodology according to Sugiyono's model, a prototype of a solar photovoltaic (PV) system was designed, validated by an expert, and tested. The prototype consisted of a 60W monocrystalline solar panel, a solar charger controller (SCC), a 12V/5Ah battery, and a 300W inverter. Testing over three days under overcast conditions in Jakarta yielded an average voltage output of 12.21–12.57V during peak sunlight hours (07:00–15:00) and sustained a 6W AC lamp load for approximately 10 hours. Expert validation scored the prototype at 100% suitability, while a trial assessment by 15 marine engineering cadets rated it at 96.25% ("suitable"). Scaling the design for onboard application, two SunPower E20-435-COM panels (435 Wp each) installed on the wing deck (123.24 m²) would generate approximately 4.35 kWh per day under an assumed 5-hour peak sun equivalent, sufficient to supply navigation deck lighting loads of 3.953 kWh/day. The resulting reduction in diesel generator load from 440 kW to 433 kW during anchorage translates to an estimated annual fuel saving of 11,542 liters of LSFO, equivalent to approximately Rp 191,597,200 per year, with a return on investment period of approximately 1.9 months against an initial installation cost of Rp 30,572,000. These findings demonstrate that solar PV integration on vessels operating in Indonesian waters is technically feasible and economically advantageous, supporting IMO MARPOL Annex VI emission reduction objectives.

Keywords: *solar cell, photovoltaic, fuel consumption reduction, shipboard power generation, MT. Hendropriyono III*

1. Introduction

The consumption of fossil fuels as the primary energy source remains a dominant practice across many industries, including the maritime sector. This reliance has accelerated the depletion of finite fossil fuel reserves and has simultaneously contributed to environmental degradation through greenhouse gas emissions, which are among the leading causes of global warming and acid rain [1]. In response to growing environmental concerns, the Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO) has revised MARPOL Annex VI to progressively reduce sulfur oxide (SOx), nitrogen oxide (NOx), and carbon dioxide (CO_2) emissions from ships [2]. IMO Tier III regulations, effective for diesel engines installed on vessels built from January 1, 2016, mandate a NOx emission limit of 3.4 g/kWh, while engines on pre-2000 vessels must comply with a 17 g/kWh threshold [3].

Compliance with MARPOL Annex VI is mandatory for all vessels entering the territorial waters of ratifying nations. Consequently, extensive research has been directed toward reducing exhaust gas emissions from ships. Among the various strategies under exploration, the development of solar cell power generation systems for onboard application has gained considerable attention [4]. The primary advantage of integrating solar photovoltaic (PV) technology lies in the reduction of fossil fuel consumption through the maximization of environmentally sustainable energy sources, coupled with improvements in internal combustion engine efficiency [5].

Solar power generation technology operates on the principle of converting photon energy from sunlight into electrical energy. Indonesia's equatorial geographical position ensures approximately 10 to 12 hours of daily sunshine, with an average solar energy potential of 4.8 kWh per square meter per day and approximately 2,000 sunshine hours annually [6]. PT. Cakra Manunggal Semesta, a maritime company actively pursuing an ecoship development program across its fleet, stands to benefit substantially from the deployment of solar power generation systems aboard its vessels, specifically the tanker MT. Hendropriyono III.

Against this backdrop, the present study aims to develop and evaluate a solar cell power generation system prototype for potential onboard application, with the ultimate objective of reducing fuel consumption and contributing to environmentally responsible maritime operations.

2. Literature Review

2.1 Electrical Power Generation

Electrical energy is a secondary form of energy derived through an extensive process encompassing generation, transmission, and distribution [7]. In the maritime context, onboard electrical power is typically generated by diesel engine generators (DEGs), also known as auxiliary engines, which convert primary energy from fuel combustion into rotational mechanical energy that subsequently drives a generator to produce electrical current [8]. Classification societies mandate a minimum of two generating sets aboard a vessel, supplemented by an emergency diesel engine generator [9].

2.2 Solar Photovoltaic Technology

Solar cells, also termed photovoltaic (PV) cells, are semiconductor devices that convert sunlight directly into electricity through the photovoltaic effect [10]. The working principle of a PV cell resembles that of a PN junction diode. When photons from sunlight strike the semiconductor material, typically silicon, they generate electron-hole pairs across the depletion region, producing a voltage differential that drives direct current (DC) through an external circuit [11]. Two primary types of crystalline silicon solar panels are commercially available: monocrystalline panels, which offer higher efficiency (up to 20.3%) but are sensitive to overcast conditions; and polycrystalline panels, which provide lower efficiency per unit area but maintain partial output under cloudy skies [12].

2.3 Components of a Solar Power Generation System

A complete solar PV system consists of several essential components. The photovoltaic module converts sunlight into DC electricity. A Solar Charger Controller (SCC) regulates the charging rate to the battery, prevents overcharging and deep discharge, and blocks reverse current flow during nighttime operation [13]. Batteries serve as energy storage devices, storing the DC electricity produced by the PV modules for later use. Inverters convert the DC output from batteries into alternating current (AC) suitable for powering conventional electrical loads at 220V/50Hz or 120V/60Hz [14].

2.4 Previous Studies

Bhattacharya et al. (2001) developed a simplified design approach for solar PV systems along with an economic analysis, comparing standalone PV systems with hybrid solar-diesel configurations. Their analysis demonstrated that hybrid system operating costs were more economical than standalone configurations [15]. Kolhe (2002) conducted a lifecycle cost sensitivity analysis comparing standalone PV systems against conventional diesel-powered generation, concluding that PV systems can provide a cost-effective energy supply option for daily energy demands of up to 15 kWh [16].

3. Research Method

3.1 Research Type and Approach

This study employed a Research and Development (R&D) methodology, which is designed to produce a specific product and evaluate its effectiveness [17]. The R&D approach was selected because the study aimed to develop a tangible product—a solar cell power generation system prototype—and to assess its functional viability for onboard electrical supply applications. A mixed-methods approach combining qualitative and quantitative techniques was adopted.

3.2 Research Model

The research model followed Sugiyono's R&D framework, which originally comprises ten steps [17]. Five steps were adapted: (1) identification of potential and problems, (2) information gathering, (3) product design, (4) design validation and revision, and (5) product testing. Phase I (Research) involved 11 months and 20 days of observational data collection during sea service aboard MT. Hendropriyono III; Phase II (Development) spanned 7 months of prototype construction, expert validation, and cadet-based product trials.

3.3 Product Design

The prototype solar PV system was designed to capture solar energy during approximately 10 hours of daylight. The system architecture comprised four primary components: (1) a monocrystalline solar panel serving as the energy source, (2) a Solar Charger Controller regulating energy flow, (3) a rechargeable battery for energy storage, and (4) an inverter for DC-to-AC conversion.

3.4 Validation and Testing

Design validation was conducted through expert judgment by a qualified marine engineer holding an ATT I certificate with over five years of sea service. The validation instrument utilized a Likert-type scale with four assessment levels: Suitable (4), Fairly Suitable (3), Less Suitable (2), and Not Suitable (1). Product testing was subsequently carried out through a limited trial involving 15 marine engineering cadets. Suitability percentages were calculated as:

Suitability (%) = (Score Obtained / Maximum Score) × 100%

3.5 Data Collection Instruments

Data were collected through observational field notes during sea service, expert validation questionnaires, cadet assessment forms, and direct electrical measurements using a digital multimeter (Sanwa CD800a) and a watt meter. Weather condition records for the testing period (July 14–16 and July 18, 2023) were sourced from Meteoprog.com.

4. Results and Discussion

4.1 Prototype Specifications

The constructed prototype comprised the following components. The specifications are presented in Table 1.

Table 1. Prototype Component Specifications

Component	Parameter	Value
Solar Panel	Max. Power	60 W
	Output DC	20 V
	Material	Monocrystalline Silicon
	Dimensions	280 × 420 × 3 mm
	Water Resistance	IP65; Conversion Rate 19.6–20%
SCC	Voltage	DC 12V/24V
	Rated Current	10 A
	Max. Solar Input	< 50 V
	Operating Temp.	−35 to 60 °C
Battery	Capacity	5 Ah
	Voltage	12 V
	Dimensions	113 × 70 × 85 mm
Inverter	Type	MS-INV300W
	Output	220–240V / 50Hz AC
	Max. Power	300 W
	DC Input	12 V

Source: Researcher's documentation, 2023

4.2 Expert Validation Results

The prototype was validated by Mr. Bambang Wahyudi, M.Mar.E., MM, a qualified marine engineer and STIP Jakarta lecturer, on July 18, 2023. All six assessment aspects—design quality, design arrangement, PV module suitability, SCC suitability, battery suitability, and inverter suitability—received the maximum score of 4 ("Suitable"), yielding a cumulative suitability percentage of 100%. The expert noted that the prototype represents a safe, efficient, and economical alternative energy technology applicable to vessels.

4.3 Prototype Performance Testing

4.3.1 No-Load Voltage Output

The solar panel was tested over three consecutive days (July 14–16, 2023) in Jakarta under predominantly overcast conditions. Voltage measurements were taken at two-hour intervals from 07:00 to 17:00. The results are presented in Table 2.

Table 2. Solar Panel Voltage Output Over Three Days (No Load)

Time	Day 1 (V)	Day 2 (V)	Day 3 (V)	Average (V)
07:00	11.96	12.27	12.41	12.21
09:00	12.23	12.45	12.69	12.45
11:00	12.20	12.49	12.65	12.44
13:00	12.37	12.60	12.65	12.54
15:00	12.43	12.60	12.68	12.57
17:00	9.43	8.64	5.24	7.77

Source: Field measurement data, July 2023

The average voltage output ranged from 12.21V at 07:00 to a peak of 12.57V at 15:00, indicating consistent performance during daylight hours despite overcast skies. The significant drop to 7.77V at 17:00 corresponds to diminishing solar irradiance approaching dusk. Panel performance is highly dependent on weather conditions.

4.3.2 Loaded Performance Test

A loaded test was conducted using a 6W AC lamp powered through the inverter. The system sustained the lamp load continuously for 10 hours before the battery reserve was depleted at the 11th hour, validating the system's viability for low-demand applications such as emergency lighting.

4.3.3 Power Calculations

Based on the prototype specifications and standard solar irradiance values, the input and output power parameters were calculated as follows:

$P_{\text{input}} = I_r \times A = 1{,}367\ \text{W/m}^2 \times 1\ \text{m}^2 = 1{,}367\ \text{W}$

$P_{\text{output}} = V \times I = 20\ \text{V} \times 3\ \text{A} = 60\ \text{W}$

Battery charge time = 5 Ah / 0.5 A = 10 hours

4.4 Cadet Assessment Results

The prototype was demonstrated to 15 marine engineering cadets. Each cadet evaluated four aspects on a 1–4 Likert scale. The results are summarized in Table 3.

Table 3. Summary of Cadet Assessment Results

Component	Total Score	Max Score	Percentage	Criteria
PV Module	58	60	96.67%	Suitable
SCC	58	60	96.67%	Suitable
Inverter	58	60	96.67%	Suitable
Battery	57	60	95.00%	Suitable
Overall	231	240	96.25%	Suitable

Source: Cadet questionnaire data, July 2023

The overall suitability percentage of 96.25% places the prototype within the "Suitable" category (76–100%), confirming appropriate product design and component selection for further development.

4.5 Onboard Application Design

4.5.1 Lighting Load Analysis

The lighting load analysis for MT. Hendropriyono III identified LED-based lighting requirements across all vessel decks. The navigation deck lighting load was selected as the target supply. The total daily energy consumption for navigation deck lighting was determined to be 3.953 kWh. The complete vessel lighting load distribution is presented in Table 4.

Table 4. Lighting Load Distribution by Vessel Area

Lighting Area	Power (kW)
Navigation Light	0.820
Group Switch Panel & Navigation Bridge Deck	0.252
Light Panel Board (C Deck)	0.389
Light Panel Board (B Deck)	0.427
Light Panel Board (A & Upper Deck)	0.587
Light Panel Board (On Upper Deck)	0.750
Light Panel Board (Engine Room)	2.906
Total	**6.130**

Source: MT. Hendropriyono III electrical load data

4.5.2 Solar Panel Selection and Energy Yield

For the full-scale onboard application, SunPower E20-435-COM monocrystalline panels were selected, each rated at 435 Wp with 20.3% efficiency and dimensions of 2,067 × 1,046 × 46 mm. Two panels were proposed for installation on the available wing deck area of 123.24 m². Assuming 5 peak sun hours per day (10:00–15:00), the estimated daily energy yield is 4.35 kWh (Table 5), which exceeds the navigation deck lighting demand of 3.953 kWh.

Table 5. Estimated Daily Energy Yield from Solar Panels

Location	Panels	Panel (W)	Total (W)	Total (Wh)	Total (kWh)
Wing Deck	2	435	870	4,350	4.35

Source: Calculated data based on panel specifications

4.5.3 Balance of System Components

A Tree TR 12V 500Ah AGM battery was selected, providing 6 kWh storage capacity. One Blue Solar Charger Controller 150/100 (rated 100A) was sufficient for the total PV current of 12.86A ($I_{sc} \times n_{PV} = 6.43 \times 2$). A pwri8k22050 inverter (10,000W continuous, 12V DC input, 220/380V AC output, 87% efficiency) was specified for DC-to-AC conversion.

4.6 Economic Analysis

The economic feasibility was assessed through initial investment analysis and fuel savings calculation. The installation cost breakdown is presented in Table 6.

Table 6. Estimated Installation Cost for Onboard Solar PV System

Component	Unit Price (Rp)	Qty	Subtotal (Rp)
Solar Panel (SunPower E20-435)	5,741,000	2	11,482,000
Solar Charger Controller 150/100	11,204,000	1	11,204,000
Battery (Tree TR 12V 500Ah)	2,534,000	1	2,534,000
Inverter (pwri8k22050)	1,364,000	1	1,364,000
Installation Cost (15%)	—	—	3,988,000
Total Initial Cost			**30,572,000**

Source: Market price survey, 2023

The fuel savings were calculated based on the reduction in diesel generator load during anchorage from 440 kW to 433 kW (7 kW reduction). Using SFOC of 189.2 g/kWh and LSFO pricing at Rp 16,600/L:

Daily saving = 7 × 0.1892 × 24 = 31.776 kg/day

Annual saving = 11,439.36 kg = 11,542 L/year

Cost saving = Rp 191,597,200/year

The ROI period was calculated at approximately 0.158 years (1.9 months). Given the estimated 25-year panel lifespan, the remaining 24.8 years represent net benefit.

5. Conclusion

Based on the analysis conducted, the following conclusions can be drawn. First, the development and testing of a solar cell power generation prototype demonstrated product suitability for onboard application, as evidenced by a 100% expert validation score and a 96.25% suitability rating from 15 marine engineering cadets. The prototype successfully sustained a 6W AC lamp load for 10 hours.

Second, the scaled onboard application design for MT. Hendropriyono III confirmed that two SunPower E20-435-COM panels (435 Wp each) can generate approximately 4.35 kWh per day, sufficient to supply the navigation deck lighting load of 3.953 kWh/day. The 7 kW diesel generator load reduction during anchorage yields annual fuel savings of approximately 11,542 liters of LSFO (Rp 191,597,200), with a 1.9-month ROI against an initial cost of Rp 30,572,000.

These findings demonstrate that solar PV integration on vessels operating in Indonesian equatorial waters is both technically feasible and economically advantageous, while contributing to compliance with IMO MARPOL Annex VI emission reduction mandates. Further research is recommended to expand solar PV coverage to the entire vessel lighting system with permanent marine-grade installation.

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