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# Design Of Utilization Of Solar Panel and Gas Turbine On The Hybrid Container Ship From Tanjung Priok Jakarta to Tanjung Perak Surabaya

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**Abstract**

Solar energy found in Indonesian waters, especially in the Java Sea, can be utilized to become electrical energy, one of which is by planning a hybrid ship. There are several combinations in the Hybrid system, for example, Gas Turbines and Solar Panels, this combination is very important to reduce exhaust emissions produced by conventional ships listed in Annex Marpol where in 2016 the maximum sulfur emission limit is 0.5%. Hybrid ships with a combined system between Solar Cell Panels and gas turbines in this study there are 640 Solar Panels, to find out the amount of solar input power to solar panels is by open the Global Solar Map website. With that, we can get different input power results per day and the biggest one occurs on the third day around 848.725 kWh/day. The overall power from the first to the last day can only cover the propeller from the gas turbine of 1261.540 kWh/day of 45700.209/day (total Jakarta-Surabaya electricity demand). With a shipping route of 438 miles, it takes 14,893 tons of LNG fuel and the emissions released by the Hybrid ship's gas turbine are 0.854 tons.

***Key words*** : Ship, Solar Panel, Gas Turbine

## 1. Introduction

Environmental issues are one of the environmental problems that must be addressed quickly so as not to have a broad and serious impact on all living things on earth. This environmental issue has emerged in recent years due to low human awareness of the environment. In 1997 the Conference of the Parties (COP) agreed with the international community to regulate global climate change, in which the document was named the Kyoto Protocol which contains legal agreements between the governments of Annex 1 countries (where the countries referred to are generally industrial countries) regarding quantitative targets for reducing gas emissions. greenhouse to implement it in 2008-2012 (Rosen 2009). To achieve the target, the Kyoto Protocol is equipped with a clean development mechanism (Oppenheimer and O'Neill 2002). The hybrid ship is the concept of combining two or more different energy sources to achieve efficiency on the ship. An example of a common diesel engine, is combined with other energy sources such as the sun (Yu, Zhou, and Wang 2018). There are several combinations in the Hybrid system, for example, Gas Turbines and Solar Panels, this combination is very important to reduce exhaust emissions produced by conventional ships (Karatuğ and Durmuşoğlu 2020). This merger is carried out by a system where there is a meeting of two energy sources to drive a particular machine. In essence, a hybrid system is a system that uses two or more different sources of energy or propulsion to propel the ship (Nuchturee, Li, and Xia 2020). Micro gas turbines can be used in combination with solar panels to become the main engine. Technological advances are increasing rapidly from year to year, so gas turbines have been widely used and applied for various purposes such as electric generators, industrial machines, airplanes, and others. Gas turbines can be installed quickly and the investment costs are relatively low when compared

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to the installation of steam turbines and diesel motors for electric power plants (Kunniyoor, Singh, and Nadella 2020). The electric propulsion system is a propulsion system that uses electrical energy to propel the ship to fuel efficiency (Uyanık, Karatuğ, and Arslanoğlu 2020). The resulting solar energy is absorbed through the Solar Panel which is located on the top container. Solar panels consist of a collection of solar cells, each of which consists of two layers silicon. The workings of solar panels are represented by each layer which is used to form an electric field so that electrons can be processed into electricity. Then the electricity is channeled to the battery to store electric power which is then sent to the electric propeller (Ducted Propeller) motor (Sahu, Gnana Sundari, and Stephen 2021). For electric power consumption using the same energy source as Electric Propulsion utilizing solar energy to be absorbed into solar panels, then flowing it to the battery through the battery charge controller to regulate the overcharging/overvoltage received on the battery, then the DC electric current is converted to AC with an inverter, after that the electricity needs on the ship are divided through the Switch Board. The working principle of the solar panel is that if sunlight hits the solar panel, the electrons in the solar cell will move from N to P so that the output terminal of the solar panel will generate electrical energy. The amount of electrical energy produced by solar panels varies depending on the number of solar cells combined in the solar panel. The output of this solar panel is in the form of direct current (DC) electricity whose output voltage depends on the number of solar cells installed in the solar panel and the amount of sunlight shining on the solar panel (Liu et al. 2017).

Then the workings of the solar panel module system when loading and unloading at the port are as follows:

1. The first thing that must be lowered during loading and unloading is the 64 solar panel modules along with their mounts which are on the top surface of the container (topmost) using a land crane.

2. After that, lower the containers on the ship using a land crane.

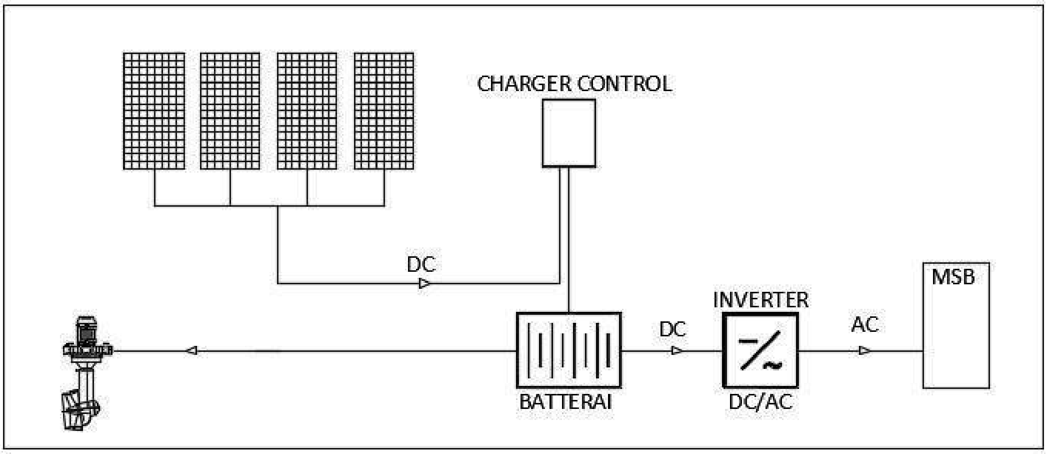



Fig. 1 Numerical model of wave energy converter.

While the gas turbine is a machine that utilizes fluid gas to rotate the turbine with internal combustion. In this machine, kinetic energy is converted into mechanical energy using compressed air which rotates the turbine wheel so that it can generate power. The most well-known gas turbine system consists of three components, namely the compressor, combustion chamber, and gas turbine (F. Haglind 2011). Air enters the compressor through the air inlet (inlet). The compressor functions to suck and increase the air pressure, so the air temperature will also increase. Then this compressed air enters the combustion chamber. Inside the combustion chamber, the combustion process is carried out by mixing compressed air and fuel. The combustion process takes place under constant pressure so can be said that the combustion chamber is only used to increase the temperature. The resulting combustion gas flows to the gas turbine through a nozzle which functions to direct the flow to the turbine blades (Alzayedi, Sampath, and Pilidis 2022). The power generated by the gas turbine is used to rotate the compressor itself and rotate other loads such as electric generators, etc. After passing through this turbine the gas will be discharged through the exhaust channel (Fredrik Haglind 2008). The hybrid ship propulsion system is a combination of ship propulsion with several engines. In addition to being able to efficiently use fuel, this hybrid system can also provide efficiency in the ship's engine room. In electric propulsion systems, it has been widely used and applies to AC motors, whereas for DC propulsion it is only converted through an inverter into AC. In a solar panel system, sunlight is captured by the solar panel and then converted into a DC, after which it passes through the Solar Charge Controller, and the electric current will be stored in the battery. The electric current stored in the battery will be distributed to equipment that requires electrical energy and one of them is an electric motor that drives the Ducted Propeller. For power storage components on this ship use batteries. The battery is a power storage device produced by solar panels when the power load from the solar panels exceeds the required load. The stored power can be used during periods of low solar radiation or at night. The battery component is sometimes called the accumulator. Batteries store electricity in the form of chemical energy. The batteries most commonly used in solar applications are maintenance-free lead-acid batteries, which are also called recombinant or VRLA (valve-regulated-lead-acid) batteries (Khan, Faruque, and Newaz 2017). Batteries serve two important purposes in photovoltaic systems, namely to provide electrical power to the system when power is not provided by the array of solar panels, and to store the excess power generated by the panels whenever that power is exceeded. The battery goes through a cycle of storing and discharging, depending on the presence or absence of sunlight. During times when there is sun, the panel arrays generate electrical power. The power that is not used immediately is used to charge the battery. During times of no sun, the demand for electric power is provided by the battery. There are several types of batteries, namely NiCD, NiCad, Li-Po, and Li-Ion (lithium) (Chen et al. 2020).

## 2. Methods

### 2.1 Data used

In determining the main size of the ship, an initial design was carried out using MAXURF software, then the type of ship that was by the designed ship was selected, where the object used in this study was a container ship with the following:

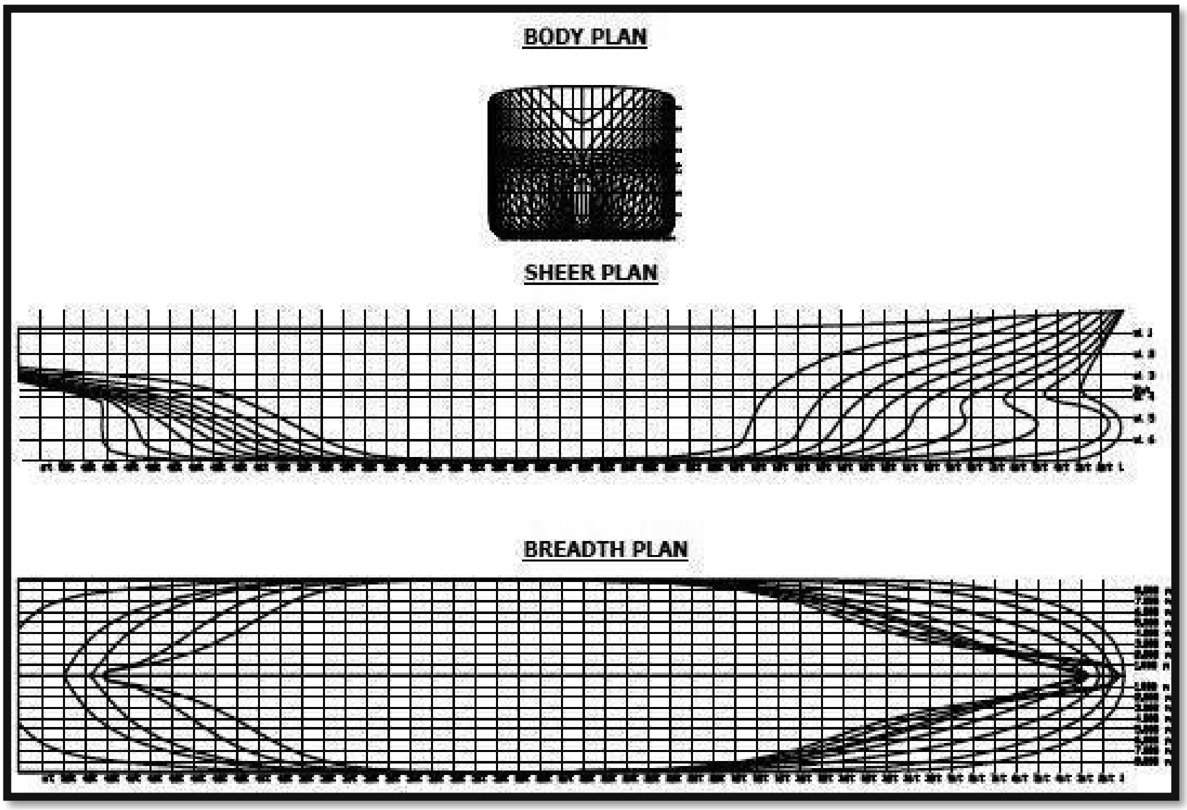



Fig. 2 Design Lines Plan Container Ship.

Principle dimension :

- Length Over All (LOA) : 160 m
- Length Between Perpendicular (LBP) : 147 m
- Draft (T) : 9,75 m
- Breath (B) : 25,60 m
- Height (H) : 17,70 m

- Velocity (Vs) : 8 *Knots*
- Route : Tanjung Priok (Jakarta) – Tanjung Perak (Surabaya)

## 2.2 The hybrid ship components

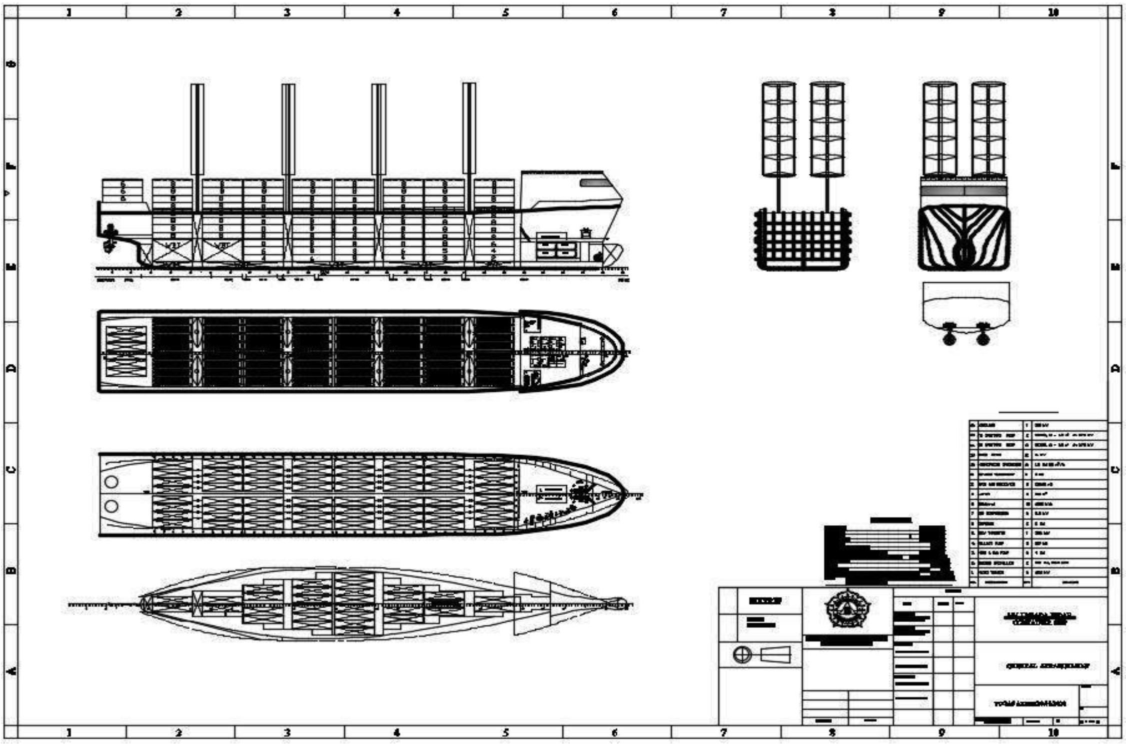


Fig. 3 General Arrangement Container Ship.

1. Solar Panels
   Solar panels are electronic components that convert solar energy into electrical energy. This PV system is usually called a module in which there are solar panels, inverters, charge control batteries, and lithium batteries.
2. Inverter.
   Inverter are a tools that can be used to change the DC input voltage to the AC output voltage input. The output of the inverter can be a regulated voltage or a fixed voltage. The inverter input voltage source can use batteries, solar power, or other DC voltage sources.
3. Battery Charge Control.
   Solar Charge Controller is an electronic equipment that is used to regulate the direct current that is charged to the battery and taken from the battery to the load. The solar charge controller regulates overcharging (overcharging - because the battery is full) and overvoltage of the solar module.
4. Lithium Battery.
   This type of battery serves to accommodate the flow of electricity converted from solar panels to batteries, which are then accumulated from the battery for electricity needs on board.
5. Ducted propeller.
   The ducted propeller, namely a propeller driven by an electric motor, where the electric motor power comes from a Gas Turbine and Battery.
6. Gas Turbines
   Gas turbines are useful for covering solar panel resources if the power generated by solar panels is not sufficient to meet the electricity needs of the ship.

## 2.3 Calculation Methods

To get the percentage of exhaust emissions on the ship. There are several stages of calculation, including(Nengah Putra, Susanto, and Suharyo 2017):

1. Calculation of ship resistance :

$$\mathrm{RT} = \mathrm{CT} \times \frac{1}{2} \times \rho \times \mathrm{S} \times \mathrm{Vs}^2 \quad (1)$$

Dimana :
CT : ship resistance coefficient
ρ : density
S : Wetted Surface Area
Vs : Velocity

2. Perhitungan Daya Kapal :

$$\mathrm{BHP} = \mathrm{SHP} + (\text{gear box losses} + \text{engine room losses} + \text{Sea Margin}) \times \mathrm{SHP} \quad (2)$$

3. Energy Ballance :

$$\text{Power} = \text{Continuous Load (CL)} + \text{Intermittent Load (IL)} \quad (3)$$

4. Power generated by Solar Panels :

$$P_G = A_G \times S \times t \times n \quad (4)$$

Dimana :
A = Area per Solar Panel
S = Average Solar Insolation
t = total panel
n = efisiensi solar panel

5. Energy Storage in Batteries :

$$\text{Battery} = \frac{2 \text{ x Total Energi}}{\text{Battery (Volt x Ah)}} \quad (5)$$

6. Determination of inverter and schematic systems :
The selection of this inverter is calculated based on the maximum load obtained at the highest absorption power of solar panels, which is 848,725 kWh/day, and has a power inverter of 150 kW. Then the number of inverters needed can be calculated through the following equation :

$$\mathrm{Ni} = \frac{\mathrm{Eac}}{\mathrm{Ei}} \quad (6)$$

Dimana :
Ni = Total Inverter
Eac = Highest energy absorption
Ei = Inverter capacity

7. Calculation of Volume and Fuel Gas Turbine :

$$W_{fo} = \mathrm{BHE} \times \mathrm{SFOC} \times \mathrm{t} \times 10^{-6} \times (1.3 \sim 1.5) ton \quad (7)$$

Dimana :
BHP : Power
SFOC : Specific Fuel Oil Consumption
t : time
t : $\frac{s}{vs}$

8. Emission of gas turbine :

$$\text{Emission} = \text{Fuel oil consumption x emission factor} \quad (8)$$

Table 1 Emission of Gas Turbine

| Higher Heating Values | Carbon Content | $CO_2$ Emission Factor | |
|---|---|---|---|
| | | Tonnes $CO_2/10^6$BTU | Tonnes $CO_2$/TJ |
| U.S Average | 14,47 | 0.05306 | 50.29 |
| 1,000 to 1,025 Btu/scf | 14,43 | 0.05291 | 50.15 |
| 1,025 to 1,050 Btu/scf | 14,47 | 0.05306 | 50.29 |
| 1,050 to 1,075 Btu/scf | 14,58 | 0.05346 | 50.67 |
| 1,075 to 1,100 Btu/scf | 14,65 | 0.05372 | 50.92 |
| 1,100 to 1,125 Btu/scf | 15,07 | 0.05526 | 52.38 |
| 1,125 to 1,150 Btu/scf | 15,09 | 0.05533 | 52.44 |
| 1,150 to 1,175 Btu/scf | 15,15 | 0.05555 | 52.65 |
| 1,175 to 1,200 Btu/scf | 15,27 | 0.05599 | 53.07 |
| 1,200 to 1,225 Btu/scf | 15,38 | 0.05639 | 53.45 |
| 1,225 to 1,250 Btu/scf | 15,52 | 0.05691 | 53.91 |
| Greeter than 1,250 Btu/scf | 16,33 | 0.05988 | 56.76 |

## 3. Result & Discussion
### 3.1 Calculation of resistance and ship propulsion

The Calculation of resistance and ship propulsion is one of the calculations carried out to determine the value of resistance on the ship and the engine capacity used by the designed ship. This affects the next planning stages, such as the planning of the engine room loading space and the size of the ship's propellers. This calculation is done with 5 speeds, namely one or two speeds each up and down from among the service speeds (Vs). Because the speed used is 8 Knots, the extrapolation method is used to get the required Total Resistance and Power. For design ship power used at a speed of 8 knots is 450 HP (335.565 KW)

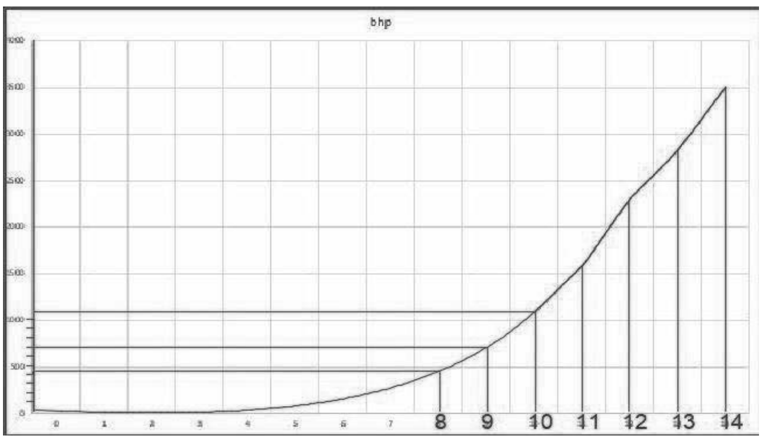


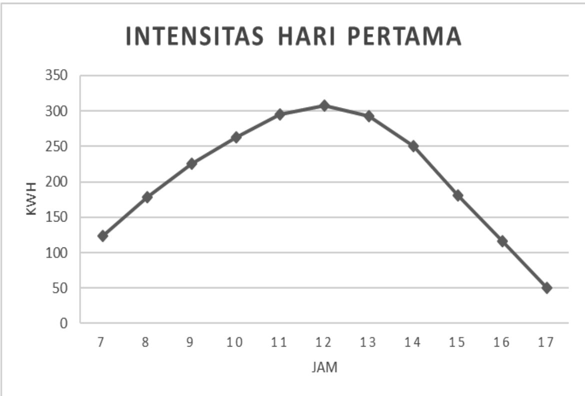

Fig. 4 Curve 5 Velocity and Power.

From the table of resistance calculation results using the method.(Sv. A A. Harvald), it can be determined and the magnitude of the propeller electrical power used for this design ship. In this design, ship uses 2 (two) main electric propellers. with the following specifications:

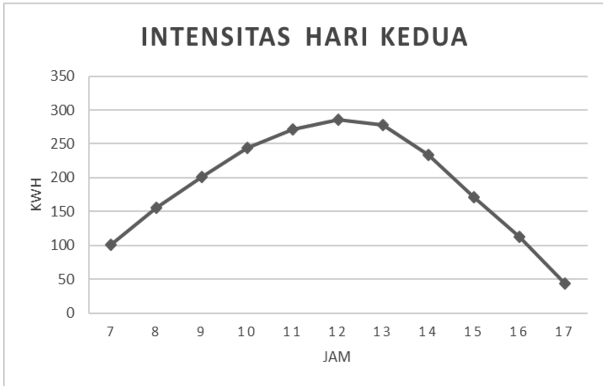
Type : Ducted Propeller
Merk : SCHOTTEL, SRP 210
Diameter : 1.45 m
Speed L Drive : 1200RPM Power : 500 kW
Quantity : 2

## 3.2 Calculation Power of Solar Panel

Below is explained the intensity of sunlight on the Jakarta-Surabaya shipping route for each day, there is the highest intensity of sunlight, namely in September. Sunlight intensity data taken from the first day to the second day is as follows :




Graphic 1
Solar Intensity Day 1




Graphic 2
Solar Intensity Day 2

## 3.3 Calculation of storage on the battery

Determining the required battery value is by looking at the maximum power requirement absorbed, which is equal to 848.725 kW, to meet these power requirements it can be assumed that the battery specifications are as follows:

Merk = LG R1000
Type = M48128P6B
Area = 12.2 x 2.9 x 2.5 m
Weight = 50 kg
Energy = 4.0 MWh = 4000 kWh

$$\text{Total Battery} = \frac{\text{Energy total solar panel} + \text{load power } x \text{ time } x \text{ 24 hour}}{\text{Power battery}}$$

$$= \frac{848{,}725 + 40{,}757 \ x \ 4{,}5 \text{ days } x \ 24}{4000 \ kW}$$

$$= 0{,}762 \text{ batteries (1 battery)}$$

### 3.4 Battery Control Charger Selection

In Charger Control, this battery is selected using the MPPT (Maximum Power Point Tracker) method, where the voltage output by the MPPT must be the same as the voltage of the solar panel itself. So that 1 MPPT charge controller is planned to be able to cover 5 parallel circuits consisting of 10 solar panels, so that an MPPT E-Tracer model ET6415N charge controller is obtained :

$$\text{Jumlah MPPT (n)} = \frac{\text{Total Solar Panel}}{\textit{Covered panel}\ \text{1 MPPT}}$$

$$= \frac{\mathbf{640}\ \boldsymbol{Panel}}{\mathbf{10}\ \boldsymbol{Panel}}$$

$$= \text{64 MPPT Charge Control}$$

### 3.5 Total Inverter Selection

The selection of this inverter is calculated based on the maximum load obtained at the highest absorption power of solar panels, which is 848,725 kWh/day/, and has a power inverter of 150 kW. Then the number of inverters needed is :

$$\text{Ni} = \frac{Eac}{Ei}$$

$$= \frac{848{,}725}{150}$$

$$= 5{,}658\ \text{(6 Inverter)}$$

### 3.6 Calculation of Fuel Tanks Jakarta - Surabaya

The Calculation of Weight and Volume of Gas Turbine Fuel is :
$Wfo = BKW \times SFOC \times t \times 10{-}6 \times (1{,}3 \sim 1{,}5) ton$
Dimana :
BHP = Power engine 960.539 kW
SFOC = Spesific fuel oil consumption 217,27 g/kw.h.
t = time
= S/Vs
Dimana :
S = Sailing Radius 438 miles. The planned tank capacity for the Tanjung Priok Jakarta ~ Tanjung Perak Surabaya route is 438 miles.
Vs = Ship's service speed of 8 knots = 1.151 miles/hour x 8 = 9.206 miles/hour
t = 438/9,206
= 47,577 hour
= 1,982 day
= 1 day 23 hour

Faktor 1,3 ~ 1,5 cadangan adalah untuk :
-Fuel rest in tanks
-Seaway

-Wind
-Waiting time

Jadi :
$Wfo$ = 960,539 × 217,27 × 47,577 × 10−6 × (1,5)
= 14,893 ton
= 14983 kg

Fuel Oil Volume (Vfo)
$Vfo = Wfo/\gamma fo$
Dimana :
$\gamma fo$ = density LNG
= 0,5 kg/liter
Jadi :
$\gamma fo$ = 14983/0,5
= 29966 liter

### 3.7 Calculation of Solar Panel Efficiency in Fuel for the Jakarta - Surabaya Shipping Route

The efficiency of solar panels on fuel for the Jakarta - Surabaya shipping route
Where :
S = 438 miles Sailing Radius.
The tank capacity is planned for the Tanjung Priok Jakarta - Tanjung Perak Surabaya as far as 438 miles.
Vs = Velocity of ship 8 *knots* = 9,206 mil/hour
= 438/9,206
= 47,577 hour
= 1,982 day
= 1 day 23 hour

Total power requirement (kW) Jakarta-Surabaya = Sailing time (hours) x total load (kW)

= 47,577 x 960,539

= 45700,209 kWh

Jakarta-Surabaya solar panel input power (kW) = First day + Second day

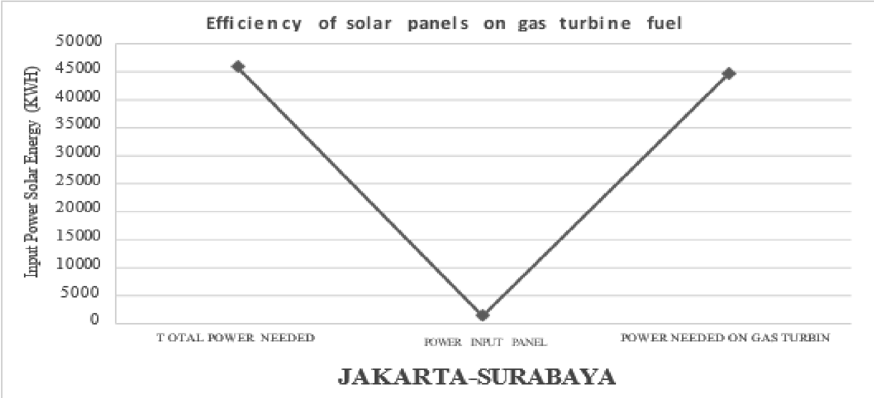
= 658,195 kWh + 603,345 kWh
= 1261,540 kWh

Total Power needed by Gas Turbine:

Input power - Total power requirement (kW) Jakarta-Surabaya =
= 1261,540 – 45700,209

= 44438,669 kW

So the power that can be covered by solar panels for the Jakarta - Surabaya shipping route is 1261.540 from 45700.209 (total power requirement (kW) Jakarta-Surabaya).




Graphic 3 Solar panel efficiency on gas turbine fuel (Jakarta-Surabaya)

### 3.8 Calculation of Solar Panel Efficiency in Fuel for the Jakarta - Surabaya Shipping Route

Calculation of CO2 emissions on LNG fuel after being covered by solar panels for the Jakarta - Surabaya shipping route is carried out with the following calculation equation :

$W_{fo}$ (Before Solar Panel Input) = BHP × $t$ × $SFOC$ × $10^{-6}$ × (1,3~1,5)$ton$
$W_{fo}$ (After Solar Panel Input) = (BHP × $t - Input\ Panel$) × $SFOC$ × $10^{-6}$ × (1,3~1,5)$ton$
Where :
BHP = 960,539 kW
Power of Solar panel = 1261,540 kW
SFOC = *Spesific Fuel Oil Consumption* from main engine 217,270 g/kw.h.
t = time
= S/Vs
Where :
S = Sailing Radius 438 miles. The planned tank capacity for the Jakarta ~ Surabaya route is 556,600 miles
Vs = Ship's service speed of 8 knots = 1.151 miles/hour x 8 = 9.206 miles/hour
t = 438/9,206
= 47,577 hour
= 1,982 day
= 1 day 23 hour

Factor 1.3 ~ 1.5 backup is for :
*Fuel rest in tanks*
*Seaway*
*Wind*
*Waiting time*

$W_{fo}$ (Before input Solar Panel) =
960,539 × 47,577 × 217,270 × 10−6 × (1,5)
= 14,893 ton = 14893 kg
Emissions = total fuel consumption x emission factor
Where :
Total Fuel Consumption = 14,893 ton
Emission factor = 0,05988
Emission = 14,893 ton x 0,05988
= 0,891 ton

$W_{fo}$ (After input solar panel) = (960,539 × 47,577 − 1261,540) × 217,270 × $10^{-6}$ × (1,5)
= 14,482 ton
= 14482 kg

Emissions = total fuel consumption x emission factor
Where :
Total fuel consumption = 14,482 ton
Emission factor = 0,05988
Emission = 14,482 ton x 0,05988
= 0,854 ton

$$\text{Percentage emission} = \frac{(0{,}891 - 0{,}854)}{0{,}891} \times 100\%$$
$$= 4.152\ \%$$

So the result of reducing the weight of CO2 emissions released by LNG fuel with panel power input for hybrid ships on the Jakarta - Surabaya shipping route is 4.152 %.

## 4. Conclusion

1. In this research, was concluded that hybrid container ships with dimensions of 160 m (LOA), 147.87 m (LBP), 147 m (LWL), 25.06 m (Width), 9.75 m (Drawn of Water) , 17.70 m (High), capable of accommodating 640 panels on the top surface of the container on the empty deck of the container ship, which has an average absorption capacity of 712.467 kWh/day with the highest absorption occurring on the first day of 658.195 kWh through the equation for calculating PG = AG x S x t x n.
2. In this study, it was determined that the amount of panel power that can cover the gas turbine to meet all the electricity needs on ships on the Jakarta - Surabaya shipping route is 44438.669 kWh or with a percentage of 2.760% of the total electricity demand for the Jakarta - Surabaya shipping route.
3. The amount of CO2 emissions from the fuel emitted by the gas turbine on this Hybrid ship is 0.891 tons for the Jakarta-Surabaya shipping route of the required 14.893 tons (total Jakarta-Surabaya fuel consumption), with an emission factor of 0.05988.

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