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SOLAR ENERGY: SOLUTION TO FUEL DILEMMA

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ABSTRACT

Fuel economy has become a major concern due to the increase of oil price. Moreover, the availability of fuels is limited and depleting as the consumption is increasing. Renewable energy became a solution to this entire dilemma. Solar energy represents one of the best alternative energy available to mitigate these challenges. This paper studies the potential of using solar Photovoltaic system onboard of an ongoing ship as an auxiliary power. Photovoltaic panels are supposed to be installed on the deck of the ship. The Average Annual Cost (AAC) due to installing the solar panels are calculated and compared with the fuel cost. Simple curves are introduced to be used to estimate the PV area, number of batteries required and the AAC for solar system. The study showed that using solar energy, as an auxiliary power, will reduce the annual cost of the ship and above all it is an environmental friendly solution which reduces the carbon emissions of the ship.

KEYWORDS: Solar Energy, Photovoltaic on Shipboard, Carbon Emissions

Nomenclature

AAC	Average Annual Cost
C_R	Capital Recovery factor
D	Inflation rate
DOD	Maximum permissible depth of discharge of the battery,
G_{av}	Average solar energy input per day
η_B	Battery efficiency
η_{Inv}	Inverter efficiency
η_{out}	Output efficiency
η_{pv}	PV efficiency
I	Rate of interest
LCC	Life Cycle Cost
N_C	Largest number of continuous cloudy days of the site
PSI	The PV peak power, at peak solar insulation
TCF	Temperature correction factor

INTRODUCTION

In the New Policies Scenario, world primary demand for energy increases by one-third between 2010 and 2035 and energy-related CO_2 emissions increase by 20%, following a trajectory consistent with a long-term rise in the average global temperature in excess of 3.5°C (1). With the increase in demand, there are not enough readily available energy sources to meet the expected growth. This is called the Energy Dilemma.

By year 2050, in the absence of policies, ship emissions could grow by 200% to 300% - compared to the emissions in 2007- as a result of the growth in world trade. A significant potential for reduction of GHG emissions through technical and operational measures had been identified, which is, if implemented, could increase efficiency and reduce the emissions rate by 25% to 75% below the current levels (2). Renewable energies are considered one of these reasonable solutions, which give energy, and at the same time gives no emissions.

The rising transport expenses due to the fuel prices, the increasing restrictions of CO_2 and nitric oxides NOx emission due to new ecological policies, and generally the need for more eco-friendly transportation were the reasons that forced the marine companies to reexamine the systematic use of PV systems on large vessels. In 1996, Katagi et al. (3) studied the use of photovoltaic system to reduce the capacity of diesel engine by 20%, which lead to No_x and Sox reduction by 15% and 17% respectively. Fonseca et al. (4) presented the preliminary design of an electric catamaran for tourist. The propulsion system included two electric motors fed by a storage and energy production system based on hydrogen fuel cell, PV panels and lithium–iron phosphate batteries. It was concluded that the PV system has a significant contribution for the daily energetic needs of the tourist ship. In the summer months, the energy converted from solar almost covers the ship energetic needs.

Lee et al. (5) proposed that the hybrid PV/diesel green ship operates not only in a stand-alone mode but also when connected to a smart grid. To commercialize the proposed green ship in the near future, a conventional passenger ship was fitted with a 3.2 kW PV system and operated during the project. The operating strategy of the hybrid PV/diesel system, stability assessment and economic analysis was discussed showing that the hybrid PV/diesel green ship is expected to be commercialized and adopted widely to a range of diesel-powered ships.

Ioannis et al. (6) presented of the most popular trends of the mainland PV technologies on the fields of solar cell types and the PV systems, and how they can be applied in ship applications. The electric grid of a typical marine vessel was described, the main parts are distinguished, the typical electric magnitudes were defined, and the preferable areas where the PV plants can be attached were spotted. The authors concluded that the PV system must be tolerant to the special marine environmental conditions and especially the wind, humidity, shading, corrosion problems, and limited installation areas.

This paper studies the possibility of fitting photovoltaic solar panels onboard of a ship to reduce dependability on fossil fuel. The electric demand of the ship is calculated and the power produced by the panels is calculated as well. Cost analysis and carbon emissions calculations are made to check the economical and environmental effect.

SOLAR ENERGY

Solar energy, radiant light and heat from the sun, has been harnessed by humans since ancient times using a range of ever-evolving technologies. Solar energy technologies include solar heating, solar photovoltaics, solar thermal electricity, solar architecture and artificial photosynthesis, which can make considerable contributions to solving some of the most urgent energy problems the world now faces. Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy.

Active solar techniques include the use of photovoltaic panels and solar thermal collectors to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air.

The photovoltaic technology can indeed be a cost effective solution for ships. PV systems can act as ideal subsidiary power sources, independent from the vessel electromechanical settlement because they:

- Produce electric power without the need of transferred gas or liquid fuel,
- Have no by-products such as gas emissions or noise,
- Have low maintenance cost,
- Have limited or no use of mechanical moving parts,
- Consist of few parts, with easy installation and fast replacement in case of aging or defectiveness,
- Have satisfactory life time with a warranted PV panel output power by the manufacturers, which usually cannot be less than the 80% of the nominal one after 25 years of operation,

According to the 1991 Egyptian Solar Radiation Atlas (7), the country averages between 5.4 and more than 7.1 kilowatt-hours per square meter (kWh/m^2) of annual daily direct solar radiation, from north to south. The annual direct normal solar irradiance ranges from 2, 000 kWh/m^{2}to 3, 200 kWh/m^2, rising from north to south, with a relatively steady daily profile and only small variations in resource. Such conditions are supported by 9–11 hours of sunlight per day, with few cloudy days throughout the year.

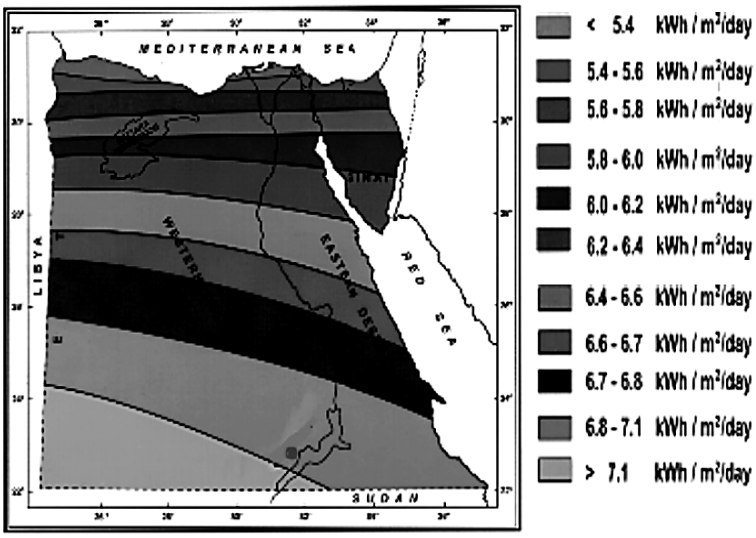

Figure 1: Solar Radiation in Egypt (3)

PV SYSTEM DESIGN

The four primary components for producing electricity using solar power, which provides AC power for daily use are: Solar panels, charge controller, battery and inverter, Figure . Solar panels charge the battery and the battery provides DC voltage to the inverter, and the inverter converts the DC voltage to normal AC voltage. If 220-240 volts AC is needed, then either a transformer is added or two identical inverters are series-stacked to produce the 240 volts. To design PV system the following steps are required:

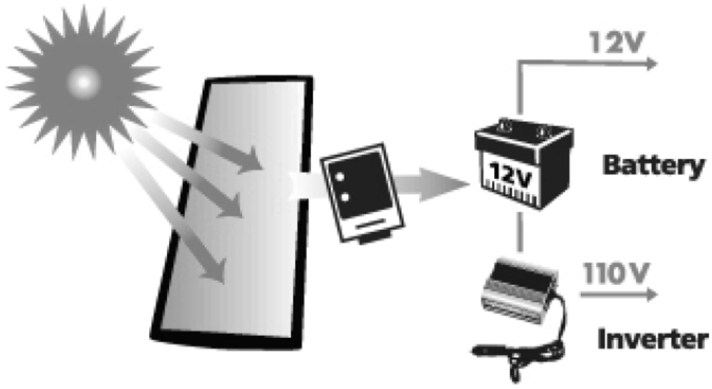

Figure 2: Solar System Components

The Average Daily Solar Energy Input

The average daily solar energy input over the year (G_{av}) can be found from the Solar Atlas that is about 5.4 to 7.1 kWh/m^2/daydepends on the area of operation (7).

The Average Daily Load Demand

The average daily load demand E_L can be calculated from the ship electrical data.

Sizing of the PV Array

The size of the PV array, used in this study, can be calculated by the following equation (1):

$$PV\ area = \frac{E_L}{G_{av} \times \eta_{PV} \times TCF \times \eta_{out}}$$ **Equation 1**

where

G_{av} average solar energy input per day

TCF temperature correction factor

η_{PV}PV efficiency

η_{out} =battery efficiency (η_B) * η inverter efficiency(η_{Inv})

It is presumed that at "peak sun", 1000 W/m² of power reaches the surface of the earth. One hour of full sun provides 1000 Wh per m² = 1 kWh/m² - representing the solar energy received in one hour on a cloudless summer day on a one-square meter surface directed towards the sun. The PV peak power, at peak solar insulation (PSI) of 1000 W/m^2, is thus given by:

PV Peak power = PV area * PSI * η_{PV} **Equation 2**

Sizing of the Battery

The storage capacity of the battery can be calculated according to the following relation

$$Storage\ capacity = \frac{N_C\, E_L}{DOD \cdot \eta_{out}}$$ **Equation 3**

NC: Largest number of continuous cloudy days of the site the largest number of continuous cloudy days N_C in the selected site is about 4 days.

DOD: Maximum permissible depth of discharge of the battery, usually taken 0.8.

Inverter

Storage batteries use and store direct current (DC) and have a low voltage output usually in the range of 12 - 24 volts. Virtually all modern appliances operate on alternating current (AC) and work on 220 volts. An inverter produces AC electricity from the DC battery to power the AC appliances, such as televisions, air conditioners, pumps, satellite communication, entertainment systems, radios and other things onboard ship. The used inverter must be able to handle the maximum expected power of AC loads. Therefore, it can beselected as25% higher than the rated power of the total AC loads.

SELECTED MODULE

In this section calculations of the PV system requirements are done. The selected PV modules are mono-crystalline silicon, with the following specifications at standard test conditions (i.e., 1000 W/m^2 and 25^{o}C):

- Peak power: 240 Watt
- Peak-power voltage: 29.6 V
- Peak-power current: 7.67 A

The ship is assumed to sail in the Mediterranean Sea, the Solar Radiation Data used in the calculations are shown in Table 1 and Equation 1.

Table 1: Solar Radiation Data

PSI	1000	W/m^2
TCF	0.8	
G_{av}	5400	Wh/m^2/day
η_{pv}	0.12	
η_{out}	0.765	

Table 2: PV System Prices

Item	Cost
PV Panel	$ 2 /W
Battery	$1/Ah
Inverter	$0.5/W
Installation	10% of PV cost
Maintenance /Year	2% of PV cost

The selected batteries are of 12 V and 300 Ah. The storage capacity is calculate from Equation 3. Since, the selected DC busvoltage is 24 V, and then the required ampere-hours of the battery equal the storage capacity divided by the bus voltage.

Table 2 shows the average prices of the PV system components in the market.

Design Curves

A set of curves are constructed to be easily used when designing PV system. Figure 1 is drawn using equations 1, 2 and 3. Figure 2 is drawn based on the average prices listed in Table 2.

One can use the demand KW to calculate the PV area and consequently the number of PV panels and necessary batteries. Alternatively, the other way around, by determining the available area onboard, one can determine the output KW of the panel. According to the available area onboard, the output of the solar system is calculated. Alternatively, according the required power, the required area can be defined.

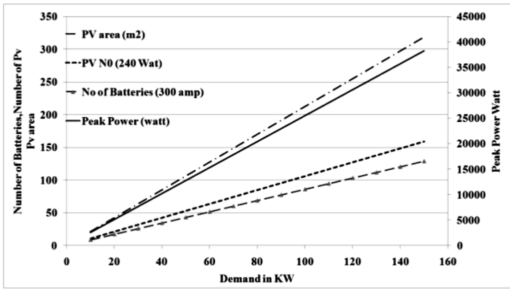

Figure 1: PV System versus Demand

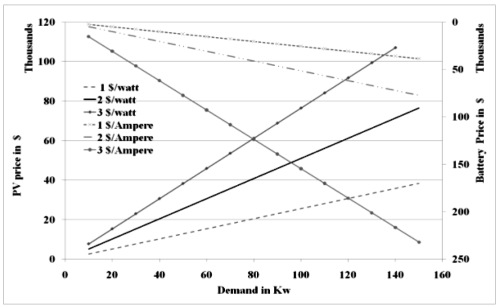

Figure 2: PV and Batteries Prices

CASES OF STUDY

Two study cases are presents in this section. The ships in the study has the below properties as shown in Table 3. Ship 1 has three generators with the properties shown in Table 4. Ship 2 has two generators with the specs in the same table. Three areas are available onboard as shown in Figure 3 for ship 1. Table 5 shows the amount of the area available. For ship 2, there is two areas suggested to be covered with solar cells as shown in Figure 4

Table 3: Ship Properties

	Ship 1	Ship 2
L_{BP}	73 m	50
B	14.5 m	15
D	9.25 m	2.5
T	5 m	1.44

Table 4: Engine Properties for Ship 1

	Ship 1	Ship 2
Output power	500 KW, 50 HZ	60 KW, 50HZ
Fuel consumption	2.5 ton / day 210 gm / KW/hr	220 gm/ KW/hr

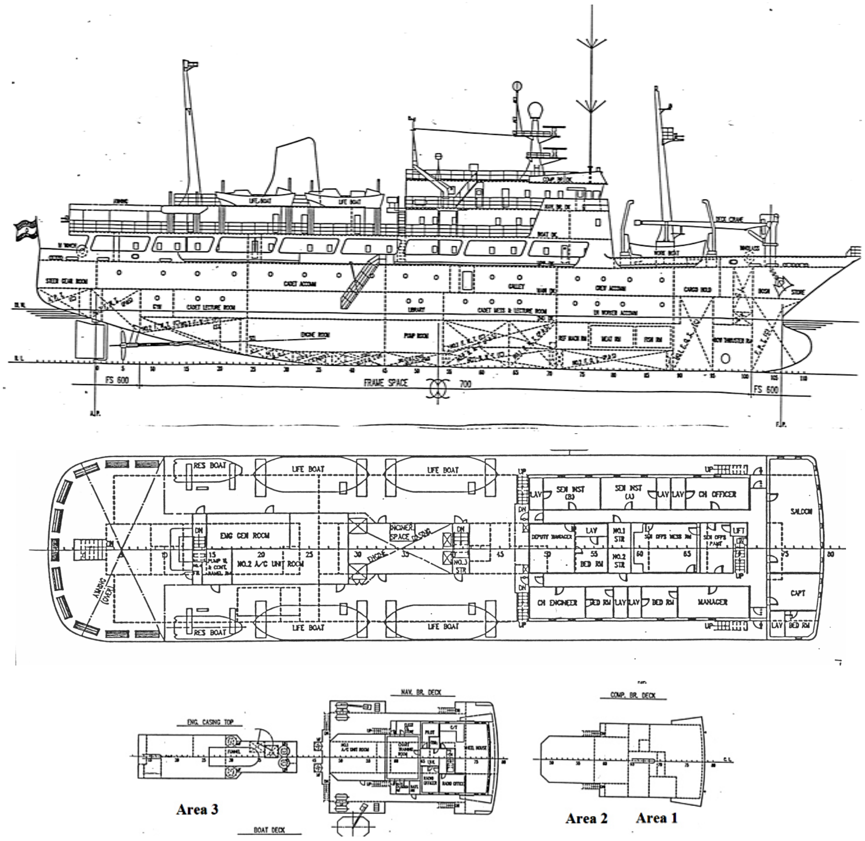

Figure 3: Available Areas Onboard Ship 1

Table 5: Available Area in Ship 1

	L	B	Area (m^2)
Area 1	11.2	9.5	106.1
Area 2	5.6	5.6	31.2
Area 3	5.6	8.9	49.9
			187.2

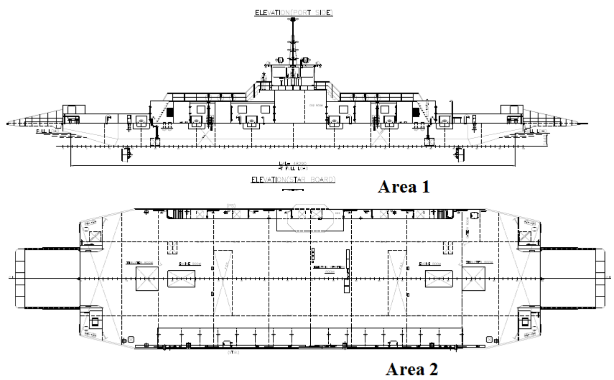

Figure 4: Available Areas Onboard Ship 2

Table 6:Available Area in Ship 2

	L	B	Area m^2
Area 1	40	0.8	32
Area 2	40	1.9	75.4
			107 m^2

"Figure 1" and Figure 2 are used to calculate the output power due to fitting solar panels in the defined Areas. The available area is ship 1 will produce 90 KW from fitting 187m^2 of solar panels with the specifications defined above. This will require 96 solar panel with 240 Watt power. This will also require 77 batteries to store the given electricity during the day.

The available areas in ship 2 will produce 60 KW, which replaces one of the generators. This requires 53 solar cell and 53 batteries. Knowing that the lifetime of the panels are 25 years, and the lifetime of the batteries are 5 years, another four groups of batteries will be purchased each 5 years.

LIFE CYCLE COST ANALYSIS

In this section, the life cycle cost (LCC) estimation of the designed PV system is discussed. The LCC of an item consists of the total costs of owning and operating an item over its lifetime, expressed in today's money. The LCC of the PV system includes the sum of all the present worth's (PW's) of the costs of the PV modules, storage batteries, inverter, the cost of the installation, and the maintenance and operation cost (M&O) of the system.

The details of the used cost data for all items are shown in Table 2. The calculation of the present worth value is made assuming rate of inflation (d) = 3% and rate of interest (i) = 10%.

The present worth of each group of batteries is calculated using the present worth factor C_{PW}considering N = 5 years:

$$C_{PW} = \left(\frac{1+i}{1+d}\right)^N$$

The Average Annual Cost (AAC) of the PV system can be calculated using the capital recovery factor C_R:

$$AAC = LCC * CR$$

where

$$CR = \frac{\left[1-\left(\frac{1+i}{1+d}\right)\right]}{\left[1-\left(\frac{1+i}{1+d}\right)^N\right]}$$

Figure 5 shows the results of the calculations. The figure shows the annual cost for different PV price. The PV price is given per Watt. This curve can be used to make rough estimation of the annual cost. Defining the output KW of the PV system and the available area onboard, from Figure 1, one can estimate the annual cost of the system. Assuming the PV panel will cost $2/watt. The PV panels price $45866 and the annual cost is $37417 /year for ship 1. The Average Annual Cost for ship 2 is $ 25481./ year.

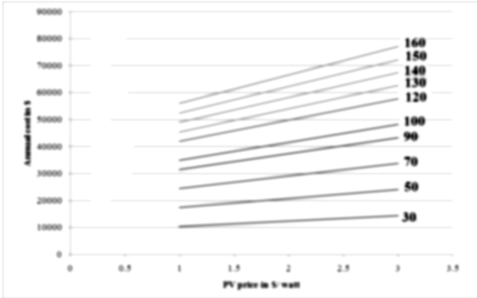

Figure 5: Annual Cost of PV System for Specified KW

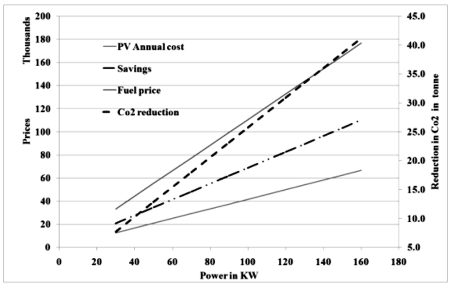

Figure 6: Saving in Cost and Reduction in Co_2

ECONOMIC AND ENVIRONMENTAL ANALYSIS

The AAC of the PV system is to be compared with the fuel consumption used to produce the required KW per year. The engine consumption is determined from the engine booklet and was found to be 210 and 220 gm/ Kw/hr, Table 4. The average Fuel price in 2013 is 600$/ ton, consequently by knowing the generator fuel consumption, one can determine the fuel consumption for the equivalent KW.

Knowing that 1 Kw of electricity produced 0.7 Kg of CO_2one can calculate the carbon foot prints of the engine (1). Figure 6 shows the relation between the required power, the AAC, the corresponding fuel price and the carbon emissions. One can conclude from the figure that using solar panel as auxiliary source of power will save money and helps in reducing the carbon foot print of the engine.

For the 90 KW produced by the PV system, the below table summarizes the results. Installing PV system on ship will save more than $6000 per year, which is equivalent to 60% of the fuel cost for the same power. For ship 2, the 55 KW solar panel will save $17000 / year which is equivalent to 40% of the fuel cost. Table 7 summarizes the results.

Table 7: Results

	90 KW	55 KW
PV annual cost	$37417	$25481
Fuel cost / year	$ 99338	$40113
Saving / year	$ 61922	$17113
Reduction in CO_2 / year	23.2 ton	10 ton

CONCLUSIONS

This paper studied the potential of using Solar Photovoltaic system onboard of ships as an auxiliary power. Simple curves were introduced to calculate the area of the PV panels, number of panels and batteries required for certain KW required, Figure 1 and Figure 2.

To check the economic feasibility of installing the PW system, the annual cost is to be determined considering the present worth value of all the components of the system. Figure 5 and Figure 6 can be used for any other case to give rough estimation bout the annual cost of PV system.

For the ships under the study, installing PV panels in area of 187 m^2 will produce 90 KW, which saves more than $60000 per year and reduces carbon emissions by 23 ton per year. And installing PV panels in 107 m^2 will save $17000 / year which is equivalent to 40% of the fuel cost.

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