Proposed Hybrid Power System for Short Route Ferries

Prijedlog hibridnog porivnog sustava za trajekte na kraćim rutama

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Summary

A fractional fuel consumption saving as well as pollution cuts will be a thinking pattern or a key concern in modern ship designs. Recent advances in technology for solar cells and photovoltaic (PV) modules have resulted in solar power being a cost-effective fuel reduction alternative for this objective. This paper is intended to provide a hybrid solar diesel power system for short-run ferries. This work proposes and emphasizes the energy efficiency, cost efficiency and minimal environmental impact of hybrid-powered ferries with solar diesel. The proposed system has been studied on the example of passenger-car ferry connecting the two banks of the Suez Canal at Port Said city - Egypt. Economic and environmental analyses have been conducted to determine and measure the advantages of the proposed system. The results show an economically viable and environmentally sustainable system if it were treated as a long-term investment. Compared to the equivalent diesel generator system, this system reduces exhaust emissions by about 375 tonnes per year. The fuel cost savings achieved are also significant.

KEY WORDS
solar energy
photovoltaic
hybrid solar diesel
emissions

Sažetak

Bilo kakva ušteda u potrošnji goriva i smanjenje zagađenja predstavljat će temelj za promišljanje ili najvažniji problem u dizajnu brodova. Novija tehnološka otkrića u području solarnih ćelija i fotonaponskih (PV) modula dovela su do toga da je solarna energija postala alternativa u smislu ekonomičnog smanjenja potrošnje goriva. U ovome radu predlaže se hibridni dizelski pogonski sustav na solarnu energiju za trajekte na kraćim rutama. U radu predlaže se i ističe energetska učinkovitost, ekonomičnost i najmanji utjecaj na okoliš trajekata na solarni dizelski hibridni pogon. Istraživanje predloženog sustava provedeno je na trajektu za prijevoz putnika i vozila koji povezuje dvije obale Sueskog kanala u gradu Port Said (Egipat). Provedene su ekonomske analize i analize utjecaja na okoliš da bi se utvrdile i izmjerile prednosti predloženoga sustava. Rezultati pokazuju da je sustav ekonomski izvediv i u skladu s održivosti okoliša ako se tretira kao dugoročno ulaganje. U usporedbi s dizelskim generatorskim sustavom, ovaj sustav smanjuje emisiju ispušnih plinova za oko 375 tona godišnje. Uštede na troškovima potrošnje goriva također su značajne.

KLJUČNE RIJEČI
solarna energija
fotonaponski
hibridni solarni dizelski
emisije

1. INTRODUCTION / *Uvod*

Nowadays, reducing exhaust gasses emitted from seagoing ships is actually one of the most important environmental concerns in the marine industry. In addition, the international regulations have become stricter on this issue. Hence, many ship operators have started to rely on alternative energy sources to reduce emissions from ships and therefore work in an environmentally friendly manner. In this regard, especially with the volatility of oil prices, renewable energy sources have become more attractive to ship owners. Since the ocean is exposed to vast quantities of sun rays, solar energy can be considered as one of the most promising energy sources in the maritime sector. It also reduces the use of fossil fuels, with consequent economic and environmental advantages.

The Photovoltaic (PV) solar system has recently been regarded as one of the most important alternative sources of energy. Hence, solar photovoltaic systems are commonly used to provide all or part of the electrical requirements on board marine units. Where many multihull marine units (catamaran and trimaran) are designed to use PV solar system as a hybrid propulsion system together with diesel generators[1]. Palmer and Sembler[2] have proposed a high-efficiency hybrid system which would generate electrical power onboard a very large crude carrier. The proposed system includes PV solar panels, a solid-oxide fuel cell, a gas turbine, a vapor generator for heat recovery and a steam turbine [2]. The results showed that the proposed system would cover only about 78 percent of the hotel load required in port. Sulaima and Saharuddin[3] tested the feasibility of using solar photovoltaic system as an auxiliary power source for the auxiliary engines of a 16.5 m long diving boat. The results indicated that some economic and environmental benefits will be achieved by using the PV solar system to cover boat power requirements [3].

Egypt receives an annual direct solar radiance of between 1950 and 2600 kwh/m^2/year [4]. In addition, its unique location within the solar belt countries makes it one of the most important countries that can benefit from applications of solar energy. These advantages have encouraged many Egyptian researchers to conduct more research on the use of solar energy in some inland units. Kotb et al. [5] focused on the exploitation of solar energy on board an inland waterway unit named "Dahabiyya" through experimental study and numerical analysis to simulate temperatures and other parameters of a hybrid photovoltaic thermal system consisting of PV solar modules and thermal units absorbing the heat produced that affects the efficiency of the PV modules. Moustafa and Essam [6] conducted a life-cycle cost analysis to check the feasibility of installing a solar photovoltaic system that generates part of the electrical load required on board the River Nile cruiser navigating between Cairo and Aswan.

There are about eight Passenger-car ferries crossing the Suez Canal during the day and linking the cities of Port Said and Port Fouad which considered the Asian part of Port Said governorate. These ferries and large numbers of seagoing ships passing through Suez Canal constitute a major source of air pollution in that region. Where, this area receives about 8.16 million tons of exhaust gasses released from seagoing ships alone annually [7]. Therefore, the aim of this paper is installing a photovoltaic / diesel hybrid power system on board one of Port Said passenger-car ferries to take advantage of the benefits of this system and to leverage the Port Said Governorate's geographical position, which stretches nine miles along the Mediterranean coast.

2. PORT SAID FERRIES / *Trajekti u Port Saidu*

Port Said ferries connect the two banks of the Suez Canal at Port Said Governorate and hold both people and cars for free all day long, see Fig. 1. The Suez Canal Authority (SCA) is responsible for the execution of orders and the maintenance & repair processes for these ferries. It doesn't take these ferries more than 10 minutes to travel from one bank to the other Suez Canal bank. Additionally, the loading / unloading cycle for passengers and cars takes about 30 minutes each trip. Two new passenger-car ferries (Tahia Misr 1 & Tahia Misr 2) were launched at Port Said Marine Yard in 2015. These ferry's new design differs greatly from that of the old ones, see Fig. 2.

Coupled with two marine diesel engines (2 x 263 kW at 1650 rpm) and 2 x 48 kW diesel generators, the new ferry "Tahia Misr 1" is powered by 2 x Voith Schneider Propellers (VSP). It also has a capacity of 140 tons, and can accommodate 36 vehicles. In addition it has 266 passenger seats on two levels. The key features of such ferry are as follows:

- Length over all = 57.00 m,
- Length over deck = 43.00 m,
- Length on load waterline = 40.40 m,

Figure 1 Old Design of Port Said Passenger-Car Ferries
Slika 1. Stari dizajn trajekata za prijevoz putnika i vozila u Port Saidu

Figure 2 New Design of Port Said Passenger-Car Ferries
Slika 2. Novi dizajn trajekata za prijevoz putnika i vozila u Port Saidu

- Moulded breadth = 15.00 m,
- Pontoon depth = 2.500 m,
- Design Speed = 12 km/h.

Unfortunately, there were no clean energy sources used to supply this unit with the electrical charge required. Therefore, in this paper, a photovoltaic (PV) /diesel hybrid power system is installed onboard "Tahia Misr 1" to boost its energy efficiency, thereby reducing both fuel consumption and exhaust gas emissions.

3. ROUTE METEOROLOGICAL DATA / *Meteorološki podaci rute*

In general, the performance of any photovoltaic (PV) system is sensitive to the meteorological and environmental characteristics of the navigation route considered. As Port Said's passenger-car ferries navigation route is fully laid in Port Said, the Egyptian solar radiation atlas is taken as a source for this kind of knowledge. The meteorological details of the navigation route considered in this analysis are shown in Table 1 [4]. Such values are fairly high and promote the installation of a PV solar power system onboard "Tahia Misr 1".

4. SOLAR HYBRID POWER SYSTEM / *Solarni hibridni pogonski sustav*

In general, solar hybrid power systems are often combine solar power with another power source. In addition, PV-diesel hybrid system is the most common hybrid power system. In most cases, diesel generators are used to cover the gap between the electric charge required and the power generated by the solar photovoltaic system. The proposed photovoltaic / diesel hybrid power system configuration is shown in Fig.3. This system fulfils the load needed for every hour in the year.

Electricity produced by solar panels and stored in the batteries has priority in supplying the candidate ferry's necessary electrical load. In such a device, the diesel generator would be turned on to act as a temporary source of power when the battery storage capacity reaches its minimum permissible level and the energy provided by solar panels is not sufficient to supply the necessary load. This mode will continue until the batteries are charged to their full capacity as the bidirectional inverter acts as a rectifier and allows for battery charging. In addition, in some situations, if the produced energy exceeds the electrical load required and the batteries are completely charged, a dump load will consume the excess energy. Therefore, the decision to charge and discharge the batteries or run the diesel generator is generally based on a comparison between the load needed and the solar panel energy generated available.

5. PHOTOVOLTAIC (PV) SOLAR SYSTEM / *Fotonaponski (PV) solarni sustav*

Any solar photovoltaic (PV) system consists mainly of four components (PV solar panels, charging controllers / solar regulators, storage batteries and solar inventers). Every component's role is set out as follows:

- Solar photovoltaic panels: they capture solar rays to generate electricity,
- Charge controllers / solar regulators: they are used to regulate the charge flowing to the batteries and prevent overcharging. They also don't allow the reverse night-time feed of the current into the solar panel,
- Storage batteries: they are used to store the excess electricity. Accordingly, they will be used when there is a lack of or no charge from solar panels,

Table 1 Route Meteorological Data
Tablica 1. Meteorološki podaci rute

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average high temperature °C	17.4	17.9	19.4	22.5	25.1	28.2	30.0	30.3	28.8	26.7	23.0	19.4
Average relative humidity %	68	66	65	64	66	67	68	68	68	65	67	69
Mean daily sunshine hours	6.9	7.3	8.6	9.8	10.9	12.0	12.2	11.8	11.0	10.0	8.7	6.6
Solar radiation kWh/m^2/day	4.13	4.94	6.41	7.61	8.4	8.67	8.36	7.82	6.67	5.22	4.22	3.64

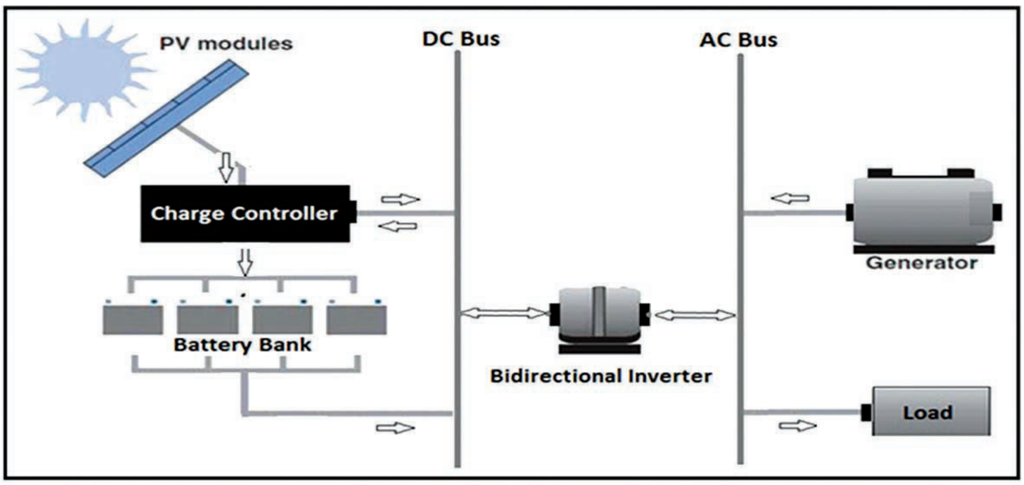

Figure 3 The Proposed Photovoltaic/Diesel Hybrid System
Slika 3. Predloženi fotonaponski/dizelski hibridni sustav

- Solar inverters: they convert the variable direct current (DC) into an alternating current (AC).

The photovoltaic (PV) solar panel efficiency is highly susceptible to both cell operating temperature (TC) and solar irradiance (G). Panel output rated power is the electrical output of a PV solar panel measured at a standard test condition (T_{STC} = 25˚C and G_{STC} = 1000W/m²). Eq. 1 is used to calculate the electrical output power generated from any photovoltaic (PV) solar panel at a real operating condition [8].

$$P_{Out-PV} = P_{R-PV} \,.\, (G/G_{STC}) \,.\, [1.0 + \alpha \,.\, (T_C - T_{STC})] \quad (1)$$

$$T_C = T_{amb} + (0.0256 \times G) \quad (2)$$

Where, P_{Out-PV} is the output electric power generated at a real operating condition in kW/h, P_{R-PV} is the output rated power of the PV solar panel in kW/h, G is solar irradiance at a real operating condition in W/m², G_{STC} is the solar irradiance at a standard test condition in W/m², α is the temperature coefficient for the maximum power at solar irradiance G, T_C is the cell operating temperature in ˚C, T_{STC} is the cell operating temperature at a standard test condition in ˚C and T_{amb} is the ambient temperature in ˚C.

$$I_{SC} = I_{SC-STC} \,.\, (G/G_{STC}) \,.\, [1.0 + \beta \,.\, (T_C - T_{STC})] \quad (3)$$

$$V_{OC} = V_{OC-STC} \,.\, [1.0 + \gamma \,.\, (T_C - T_{STC})] + \delta \,.\, \ln(G/G_{STC}) \quad (4)$$

Also, Eq. 3 and Eq. 4 are used to calculate both the short circuit current (I_{SC}) and open circuit voltage (V_{OC}) of a PV solar panel at real operating conditions, respectively [8]. Where, I_{SC-STC} is the short circuit current of a PV solar panel at a standard test condition in Amperes and β is the temperature coefficient for the short circuit current at solar irradiance G, V_{OC-STC} is the open circuit voltage of a PV solar panel at a standard test condition in Volts, γ is the temperature coefficient for the open circuit voltage at solar irradiance G and δ is the temperature coefficient for the irradiance. According to the manufacturer's instructions for 340W mono-crystalline silicon PV solar panels, α, β, γ and δ can be taken -5.5 x 10^{-3}, 3.0 x 10^{-4}, -3.6 x 10^{-3} and 2.596 x 10^{-2}, respectively.

Table 2 Specifications of a 340 W Mono-Crystalline Silicon PV solar panel at STC

Tablica 2. Pojedinosti 340 W Mono-Crystlline Silicon solarnog panela na STC

Model	JX156-72M Series
Price	0.37 $/W
Maximum power (P_{max})	340 W
Open circuit voltage (V_{oc})	46.91 V
Short circuit current (I_{sc})	9.41 A
Voltage at Pmax (V_{mp})	38.17 V
Current at Pmax (I_{mp})	8.91 A
Module Efficiency	17.61
Size	1956 x 990 x 40 mm
Weight	23.5 kg
Life span	25 Years

In the present paper, 76 mono-crystalline PV solar panels are used to cover an area of 148.5 m² available on the top deck of Port Said passenger-car ferry "Tahia Misr 1". Table 2 displays selected panel specifications in standard test condition [9]. Based on the geographical characteristics of the navigation route of "Tahia Misr 1" and the manufacturing specification of the selected solar panels, Eq. 5 is used to calculate the daily output electrical power of the installed PV solar system (E_d) in kWh [6], see Fig. 4.

$$E_d = P_{Out-PV} \,.\, N_P \,.\, T_{SS} \,.\, \eta_B \,.\, \eta_{Inv} \quad (5)$$

Where, N_P is the number of PV solar panels, T_{SS} is the daily sunshine hours, η_B is the efficiency of the battery and η_{Inv} is the inverter efficiency. In this paper, η_B and η_{Inv} are taken equal to 0.85 and 0.9, respectively [10].

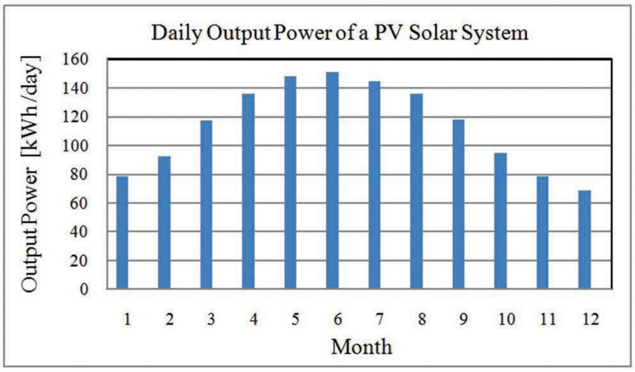

Figure 4 Daily Output Power of the Proposed PV Solar System

Slika 4. Izlazna snaga predloženog PV solarnog sustava po danu

The results also show that the proposed PV solar system would generate 41,483.5 kWh of electrical power per annum. In addition, maximum short circuit current (I_{SC}) and the maximum daily output electrical power (E_d) are equal 7.345 A and 150.934 kWh, respectively. Other components of that system are therefore selected to match those quantities. Charge controllers are typically classified according to the amount of I_{SC} they can receive from the PV solar panels. In addition, a 15% margin can be used to cover the excess that may occur in the PV solar panel output. Thus, 12 charge controllers of 60 A are used in the present paper to handle a short-circuit current of 670 A (7.345 A x 76 panels x 1.2). Table 3 shows the manufacturing specifications for the selected charge controller [11].

Table 3 Specifications of a 60Amps solar charge controller

Tablica 3. Pojedinosti 60 Amps solarnog regulatora naboja

Type	MPPT Solar Charge Controller
Maximum Output Current	60 A
Maximum input Voltage	150 V
System Voltage	12V 24V 36V 48V
Height x Width x Depth	313 x 230 x 91 mm
Weight	3.62 kg
Price	$178

Solar batteries are usually rated in ampere hours (Ah) that specifies the amount of current in Amps that the battery can deliver in hours over a specified period of time. In addition, lead acid solar battery is the most common type of battery that is used in the maritime industry. Thus, in the present case, a battery bank consisting of 54 lead acid solar batteries each 12V 300Ah is used to store 150.934 kWh electricity, which is the maximum daily electrical output of the installed PV solar panels. Battery tank size is calculated using a discharge battery depth (DOD) of 80 % [12]. Table 4 shows the manufacturing specifications for the selected battery [6].

Table 4 Specifications of a 12V 300Ah solar storage deep cycle battery

Tablica 4. Pojedinosti 12 V 300 Ah solarne duboko cikličke baterije

Type	Lead-Acid Batteries
Nominal Capacity	300 Ah
Nominal Voltage	12V
Size	522 x 240 x 242 mm
Weight	63 kg
Price	$ 270
Battery Life Time	8-12 years

Table 5 Specifications of a 5000W Solar Inverter

Tablica 5. Pojedinosti 5000 W solarnog invertera

Type	DC/AC inverter
Input voltage	DC 12 Volt
Output voltage	AC 220Volt
Continuous output power	5000 Watt
Output waveform	Pure sine wave
Output Frequency	50 Hz
Size	544 x 199 x 146 mm
Weight	12.1 kg
Price	$ 578

The battery bank stores low-voltage DC current, typically around 12-24 volts. In addition, most of the onboard ship's existing appliances are powered by AC power source and operate at 220 volts. Any solar PV system must therefore include inverters to convert DC to AC, and vice versa. The inverter 's input rating should never be less than the total appliance capacity. Inverters also need to have the same nominal voltage of the battery chosen. According to the candidate ferry's electric power balance sheet "Tahia Misr 1", the current appliances' total power equals 86.7 kW. In practice, 15-20% oversize of the inverters is recommended. Pure sine wave inverter is also the most commonly used type of inverter in marine applications. Therefore, 20 pure sine wave inverters each 5000W are used for the candidate ferry to handle a power of 99.7 kW (86.7 kW x 1.15). Table 5 shows the manufacturing specifications for the selected inverter [6].

6. ECONOMIC ANALYSIS / *Ekonomska analiza*

In the present paper, a life cycle cost (LCC) is calculated and annualized to predict the installed PV solar system's average annual cost (AAC), as follows [13]:

$$AAC = CR \,.\, LCC \tag{6}$$

$$CR = \frac{i \,.\, (1+i)^n}{(1+i)^n - 1} \tag{7}$$

Where, CR is capital recovery factor, i is interest rate and n is the life span of the installed PV solar system. The cost of the life-cycle of any PV solar system is usually equal to the sum of the present cost values:

- PV solar panels,
- Charge controllers,
- Storage batteries,
- Solar inverters,
- Installation,
- Maintenance & repair.

The life span of all components of this system is presumed to be 20 years except that of the group of solar batteries which is considered to be 10 years. Hence, the group of solar batteries installed must be replaced after 10 years. The present cost value of the second group of batteries shall be determined as follows [6]:

$$C_{B2PW} = C_{B1PW} \,.\, (1+d)^{n-1} \,.\, PW \tag{8}$$

$$PW = \frac{1}{(1+i)^n} \tag{9}$$

Where, C_{B1PW} and C_{B2PW} are the present values of the first and second solar batteries groups, respectively. Also, PW is the single present worth factor, d is inflation rate and n is the life span of each batteries group. Values of 5% and 10% for inflation and interest rates, respectively, can be considered. In addition, installation and maintenance costs are taken 10% and 2% of the cost of PV solar panels, respectively [10]. The total present values of the cost of maintenance & repair (C_{MRPW}) can therefore be calculated as follows [6]:

$$C_{MRPW} = 0.02 \,.\, C_{PV} \,.\, SPW \tag{10}$$

$$SPW = 1 \,/\, CR \tag{11}$$

Where, C_{PV} is the cost of PV solar panels and SPW is series uniform present worth factor. Now, as shown in Table 6, present values of the components of the installed PV solar system, LCC and AAC are calculated and summarized.

Table 6 Cost Calculation for the Installed PV Solar System

Tablica 6. Izračun troškova za ugrađen PV solarni sustav

No.	Items		Present value ($)
1	PV Solar Panels		9560.8
2	Charge Controllers		2136
3	Solar Batteries	1st Group	14580
4		2nd Group	8720.36
5	Inverters		11560
6	Installation		956.08
7	Maintenance & Repair		1628
8	Total present value	LCC	49141.24
9	Average annual cost	AAC	5771.86

In order to check the economic feasibility of a solar PV system producing 41,483.5 kWh per year, it is necessary to calculate annual cost of the fuel consumed to generate the same amount of electricity by diesel generators. As mentioned earlier, Port Said's new passenger-car ferry "Tahia Misr 1" is equipped with 2 x 48 kW diesel generators. Each diesel generator can cover the electrical load required for such ferry, and consumes 15 litres of fuel per hour. A 48 kW diesel generator would therefore generate 41,483.5 kWh of electricity per year, if it operates 864.24 hours per year (41,483.5 kWh / 48 kW). In addition, 17284.8 litres of diesel fuel would be used during its operating period. If the average price of diesel fuel is $1.0/litre worldwide, the price of the fuel consumed will be $17284.8 per year. Hence, it can be said that this system is economically feasible and can save $11512.94 annually.

7. ENVIRONMENTAL ANALYSIS / *Analiza utjecaja na okoliš*

To evaluate the environmental benefits of the proposed photovoltaic/diesel hybrid system, an annual decrease in "Tahia Misr 1" released exhaust gases is estimated. These calculations are based on the amount of the fuel consumed to generate 41,483.5 kWh of electricity per annum (17284.8 litres or 14.433 tons of marine diesel fuel) and the exhaust gas emission factors as shown in Table 7 [14].This paper takes into account nitrogen and sulphur oxides, carbon monoxide, carbon dioxide, and particulate matter. Where, they are the main harmful emissions from marine diesel engines.

Table 7 Quantification of Exhaust Gases Emissions
Tablica 7. Izračun emisije ispušnih plinova

Pollutants	Emission Factors in kg/(tonne fuel)	Emission Quantities in tons / year
NO_X	54.182	0.782
CO	3.687	0.053
CO_2	3179	45.88
PM	1.843	0.0266
SO_X	8	0.115
Total		46.86

Table 7 shows that the proposed "Tahia Misr 1" system would reduce the volume of exhaust gasses generated annually by 46.86 tons. Moreover, if that system is generalized to the rest of the passenger-car ferries in Port Said, the annual reduction in exhaust emissions will exceed 375 tonnes.

8. CONCLUSION / *Zaključak*

The rapid development of solar cell technology, which combines low prices with improved efficiencies, makes solar energy the most promising energy source and it can be widely used in the maritime field. Thus a photovoltaic PV / diesel hybrid power system is proposed in this paper to supply the auxiliary power needed for the instrument on board Port Said's "Tahia Misr 1" passenger car ferry. This system would ensure a continuous supply of power if both generators faced a failure or some emergency.

The results showed that if it were handled as a long-term investment, the proposed photovoltaic PV / diesel hybrid power system is economically feasible. Where, this system will produce an annual fuel cost reduction of about $17284.8. Moreover, if it generalized to all Port Said passenger-car ferries, it could also reduce the amount of exhaust gas emitted by more than 375 tons per annum. That sum may be low but if it is considered for a long time, reducing the exhausts gasses produced will also help to save our atmosphere from pollution.

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Nomenclatures / *Nazivlje*

AAC	Average annual cost, $/year
AC	Alternating current, Amps
CO	Carbon monoxide
CO_2	Carbon dioxide
C_{B1PW}	Present value for the cost of the first batteries group, $
C_{B2PW}	Present value for the cost of the second batteries group, $
C_{MRPW}	Total present value for maintenance and repair cost, $
C_R	Capital recovery factor
C_{PV}	Cost of photovoltaic solar panels, $
DOD	Battery depth of discharge
DC	Direct current, Amps
d	Inflation rate
E_d	Daily output electrical power of a photovoltaic solar system, kWh
G	Solar irradiance at a real operating condition, W/m^2
G_{STC}	Solar irradiance at a standard test condition, W/m^2
I_{SC}	Short circuit current of a PV solar panel at a real operating condition, Amps
I_{SC-STC}	Short circuit current of a PV solar panel at a standard test condition, Amps
i	Interest rate
LCC	Life cycle cost, $
NO_X	Nitrogen oxide
N_P	Number of PV solar panels, panels
n	Life span, years
PM	particulate matter
PV	Photovoltaic
P_{Out-PV}	Output electric power of a PV solar panel, kW/h
P_{R-PV}	Output rated power of a PV solar panel, kW/h
PW	Single present worth factor
SCA	Suez canal authority
SPW	Series uniform present worth factor
SO_X	Sulfur oxide
T_C	Cell operating temperature at a real operating condition, °C
T_{SS}	Daily sunshine hours, h
T_{STC}	Cell operating temperature at a standard test condition, °C
T_{amb}	Ambient temperature, °C
VSP	Voith Schneider Propeller
V_{OC}	Open circuit voltage of a PV solar panel at a real operating condition, Volts
V_{OC-STC}	Open circuit voltage of a PV solar panel at a standard test condition, Volts
η_B	Efficiency of solar batteries
η_{Inv}	Efficiency of solar inverters
α	Temperature coefficient for maximum power at solar irradiance G
β	Temperature coefficient for short circuit current at solar irradiance G
γ	Temperature coefficient for open circuit voltage at solar irradiance G
δ	Temperature coefficient for the irradiance G