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Design and Fabrication of an Automated Solar Boat

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Abstract

Environment awareness has been developed worldwide so progressively and turns into the crying needs over the last few decades. Researchers in all disciplines have a particular obligation of development which is environmentally friendly and lead towards sustainable future development. Solar energy is a prodigious renewable energy source which has enormous energy existing as heat and light and can convert it into electricity. Besides the domestic uses, solar power can be utilized as the alternative of the oil in boat's fuel and capable of minimizing the water pollution and fuel cost as well. The purpose of this research is to design and fabricate a boat based on solar power. The boat will be conducted by the energy processed from solar by minimizing environmental pollution and fuel cost. Besides, for any cloudy or emergency condition, a backup power system integrated with the photovoltaic cell will drive the boat to make the system more secured. Both mechanical and electrical part of the boat has been designed which is found more reliable, efficient and economic.

Keywords: *Boat material; photovoltaic system; renewable energy; solar boat; solar energy*

1. Introduction

With the increasing population of the world, researchers should think about alternate sources of energy because primary sources of fuel are limited in stock. So the scientists are looking for sustainable energy sources like sun, wind, water and tidal flow. Of them solar energy is the prime source of renewable energy as it can get easily from nature. The country which has enormous solar energy potentiality can think to use it in diversified sectors. Specially, the developing and least developed country can think solar energy as a cardinal source of energy to meet energy scarcity. Alike the household solar cell and solar car, solar energy also can be a smart choice to drive the boat. Some lowland countries like Bangladesh, Indonesia and Maldives can use this kind of solar boat for its inland navigations [1]. The fabrication and installation of this solar boat is very simple and reliable. Considering the economy, fuel consumption, capacity, complexity and reliability solar energy driven boat is an innovative invention. This paper tries to find a noble approach to design and fabricate a solar powered boat that can satisfy the requirements of short transportation. The boat has a navigation capacity of 25km/Day with maximum total weight of the unit of 200kg. The proposed solar boat has two batteries which can provide power in short cloudy periods as if it can be a reliable source of transportation.

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2. Boat Sheet Specification

2.1. Main dimensions

Different parts and overall dimension have been depicted in the following Table 1. According to the dimension, a general view to visualize the solar boat has been illustrated in the Figure 1.

Table 1. Different parts sizes of the solar boat.

Variable	Description	Dimension (m)
Loa	Length over all	4.50
Lhull	Length hull	4.00
Lwl	Length water line	3.50
Boa	Breadth overall	1.92
Bhull	Breadth hull	1.50
Bwl	Breadth waterline	1.30
D	Depth	0.45
T	Drought at design	0.23
H	Height	1.65

2.2. Hydrostatic/Hydrodynamic

Table 2. Hydrostatics and hydrodynamics data of the boat

Lsw	Light ship weight	200 [kg]
Dw	Deadweight	160 [kg]
Vdesign	Volume at design draught	0.360 [m]
P	Density of freshwater	1000 [kg/m2]
Δdesign	Displacement at design draught	360 [kg]
Cb	Block coefficient	0.345
Fn	Froude number	0.358
Gm	Gm for heel φ=0o	0.12 [m]

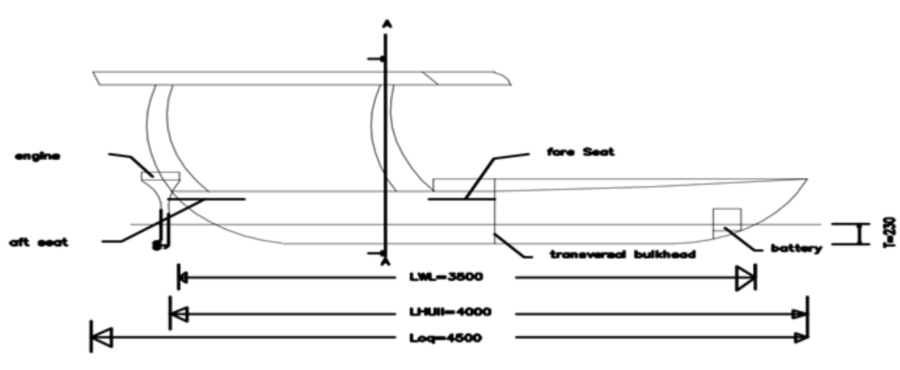

Figure 1. General view of solar boat dimension in centimeter

2.3. Propulsion

Table 3. Propulsion data of the solar boat

Notation	Description	Appearance
V_{max}	Maximum speed	4 [kn]
P_{max}	Max. Engine power output	2.7 [kw]
A	Area solar panels	7 [m^2]
U/C	Voltage and capacity of the 2 batteries	24 [V] / 84 [Ah]

3. Boat Material

In order to maintain the light weight for the light ship weight (LSW) it is necessary to use light composite materials. Though the light composite material is quit expensive, but it reduces the boat weight and increase passenger carrying capacity.

Table 4. Propulsion data of the solar boat

Resin	Reinfor-cement	Density [kg/m3]	Tensile Strength [Mpa]	Tensile Modulus [Gpa]	Comp. Strength
Epoxy	Aramid WR	1330	517	31	172
Polyester	E-Glass uni	1800	410-1180	1241	210- 480

Hull, bulkheads, pillars, deck, seats and roof are out of the very light Aramid WR. This has relative good material characteristics compared to the weight. The keel which has to contain the main forces and moments is out of the very strong E-Glass uni material [2].

3.1. Different element weight

For the determination of the weights was the hull shape approximated with geometrical surfaces like ellipses and parabolas and also with geometrical bodies like ellipsoids and parabola. For the preliminary design the precision of this method should be enough. For the following design steps however more accurate calculation methods are necessary like, *e.g.*, SIMPSON [2].

Table 5. Weight of the different parts of the boat

Element	Surface [m^2]	Thicknes s [m]	Volume [m3]	Density [kg/m^3]	Material	Mass [kg]
Hull aft	6.86	0.005	0.0343	1330	Aramid wr	5.62
Hull fore		0.005	0.0030	1330	Aramid wr	4.07
Flat keel	0.21	0.02	0.0042	1800	E-glass uni	7.54
Bulkhead trans.	0.49	0.005	0 .0024	1330	Aramid wr	3.28
Bulkhead long.	0.83	0.005	0.0041	1330	Aramid wr	5.52
Deck	2.76	0.004	0.0082	1330	Aramid Wr	4.68
Roof	4.27	0.003	0.0128	1330	Aramid wr	7.04
Pillar		0.003	0.0007	1330	Aramid wr	1.01
Seat	0.53	0.005	0.0007	1330	Aramid wr	1.01

Table 6. Total weight calculation of the solar boat

Element	Mi [kg]
Hull	49.69
Flat keel	7.54
Deck	14.68
Bulkhead transversal	3.28
Bulkhead longitudinal	5.52
Roof	17.04
Solar panel deck	16,56
Solar panel roof	25.62
2 fore pillars	2.01
2 aft pillars	2.01
Engine	22.00
2 batteries	30.00
Fore seat	1.01
Aft seat	1.01
	Σ= 198

The difference of 2kg between the denoted 200kg LSW in the data sheet and the 198kg LSW in this table is used as a reserve. This paper contains a preliminary design. For this reason the weights were calculated with simple approximations. That means it will probably be variations in the weight during the following design stages. The reserve of 2kg acts as a security factor to make sure that the total weight of the boat is less than the required 200kg.

4. Boat Propulsion

To approximate the needful power for the propulsion system, similar boats were compared to each other. The effort to use the Admiralty coefficient was not effective:

$$Cadm = \frac{\Delta^{\frac{2}{3}} V^3}{pb}$$

Table 7. Propulsion data of different types of boat

Boat	L [m]	Δ [kg]	V [kw]	Pb[kw]	Cadm
Woolwich 20	5.9	1000	5.8	2.4	8130
Electric Boat	4	280	4.9	0.3	6784
Frauscher 560 Valencia	5.6	650	-	4.3	-
Frauscher 1500 W	5.4	350	-	1.5	-
Terhi (FI) Sea Fun C	4.06	185	-	2	-
Frauscher 600 Riviera	6	1400	5	4	3911

Mean values: = 5.16m; = 644kg; = 5.2kn; = 2.4kw

The Admiralty coefficient which is a crude but useful method of estimating power doesn't give any helpful values in this case. The main reason for that are probably the strong distinctions in the used values. As this method is confined to cases where the change in speed (V in kn) and displacement (Δ in kg) is relatively small. Besides the big distribution from the admiralty coefficients the table shows that the Boat is with a length L of 4.50m, a displacement Δ of 360kg and an engine power Pb of 2.7 kw for a speed V of 4 knots well equipped.

5. Solar Energy

Solar energy can be calculated according to the geographical position, solar panel area and solar panel efficiency [3]. For the practical implementation, solar energy data has been calculated according to the solar intensity of Bangladesh. The quantity of average solar energy in all seasons in Bangladesh is 1kw per $1m^2$ terrestrial surfaces. Mono crystalline solar cells are able to convert 20 % of the incoming solar energy into electrical energy:

$$1\frac{KW}{m^2} \times 0.20 \times 7.03m^2 = 1.41\,KW$$

The solar panels on the boat can provide 1.41kw, as illustrate in the above equation.

Table 8. Solar energy data

Solar constant (terrestrial)	1 kw/m^3
Effectiveness η of the solar panels	20 %
Surface of the solar panels	$7.03m^3$
Area weight solar panel	6 kg/m^3

6. Batteries

The boat contains the batteries of the following type as show in the Table 9.

Table 9. Batteries specification

Manufacturer	Voltage/Capacity [V/Ah]	Dimensions(length x breath x height) [mm]	Weight [kg]
DETA GEL	12/42	197 x 166 x 175	15
Total	24/84	-	30

The batteries are installed in the fore part of the boat. One stands on the portside and the other one on starboard. To ensure a good maintenance for each battery is a hatch in the deck installed [4]. With the two batteries the boat can store the solar energy. So it has propulsion even under non-perfect weather conditions.

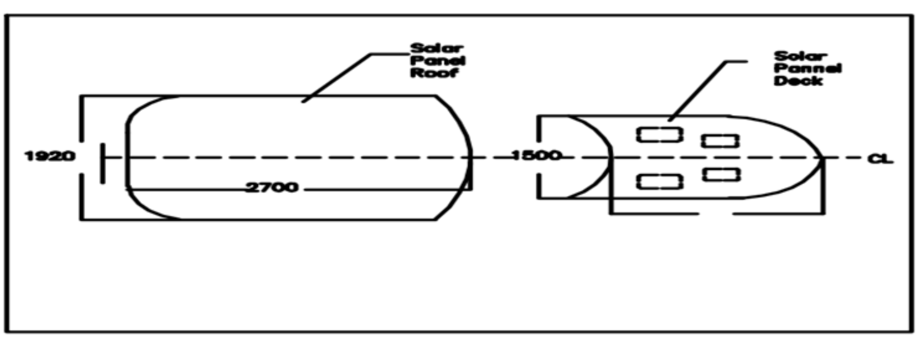

Figure 2. General view of the solar panel dimensions in centimeters

7. Engine

Karvin 2700 engine has been chosen for the solar boat. The main advantage of this engine is that it can operate in direct current and has flexible options to speed control.

Table 10. Specification of KARVIN 2700 engine [5]

Amp hour rating min	80 Ah battery
Battery voltage	24V/36V/48V
Rpm max.	900 / 1200 / 1500
Power max. Kw/Hp	2.7 / 3.6
Torque	27.5 nm
Shaft length	long shaft l (510mm) / short shafts (380mm)
Continuous regulation	Yes
Forward and reverse	Yes
Engine weight	22kg
Electronics	electronic control + electronic safety key

8. Boat Stability

For the determination of the centers of gravity of the sections valid the same as for the weight, no numerical methods were used during the preliminary design. That results in the fact that all the given data are approximations and may change in the following design steps.

Table 11. Stability data analysis

Element	Mi [kg]	Xcgi [m]	Mi x Xcgi [kg.m]	Zcgi [m]	Mi x Zcgi [kg.m]
Hull	49.69	1.77	88.05	0.15	7.50
Flat keel	7.59	2.07	15.59	0.08	0.57
Deck	14.68	2.93	32.23	0.45	6.61
Bulkhead trans.	3.28	2.80	6.57	0.32	1.05
Bulkhead long	5.52	2.91	16.06	0.25	1.40
Roof	17.04	1.00	17.04	1.65	28.11
Solar panel deck	16.56	2.93	48.46	0.45	7.45
Solar panel roof	25.62	1.00	25.62	1.65	42.27
2 fore pillars	2.01	1.50	3.02	0.85	1.71
2 aft pillars	2.01	0.06	0.12	0.85	1.71
Engine	22.00	3.18	69.96	0.23	5.06
2 batteries	30.00	2.80	84.00	0.09	2.70
Fore seat	1.01	1.83	1.84	0.40	0.40
Aft seat	1.01	0.18	0.18	0.40	0.40
2 persons	160.00	1.00	160.00	1.20	192.00
Σ=	354.29	X_{cg}=1.63	582.09	Z_{cg}=0.84	298.93

9. Calculation of GM (heel φ = 0o)

$$GM = KB + BM - KG$$

The distance between the base line K (Z = 0m) and the centre of buoyancy in z-direction (ZCB) equals to:

$$KB \sim \frac{2}{3}T - \frac{2}{3} \times 0.23\,m - 0.15m$$

The distance between the centre of buoyancy in z- direction (ZCB) and the Meta centre (M) equals to:

$$BM = \frac{I_T}{V} \sim \frac{L \times {}_{B}^{\hat{}}3}{12 \times V} = \frac{3.5m \times (1.0m)^3}{12 \times 0.360m^3} = 0.81m$$

So the initial stability is:

$$GM = KB + BM - KG = (0.15 + 0.81 - 0.84)m = 0.12\ m$$

The initial stability was calculated considering 2 persons with a weight of 80 kg/person stand in the aft part of the boat. This was defined as the worst possible loading case. With a GM of 0.12m is the initial stability good.

10. Strength

Strength Considering the longitudinal strength the flat keel (50mm x 20mm) is the most important component of the boat. It is designed for lakes and rivers. So it will not be subject to the strong torsion and bending moments which can be created from heavy sea motions. But an inconvenient distribution of the deadweight in the boat can also cause significant torsion and bending moments [6]. The main structure that provides strength in the hull of the boat consists of:

- The flat keel (general longitudinal strength)
- The transversal bulkhead (receives torsion moments from the hull)
- The seats (prevent the twist of the hull through the reduction of the deck opening degree)
- The longitudinal bulkhead (prevents the warping of the transversal bulkhead and connects the keel with the deck).
- And the deck (prevents the twist of the hull and receives also the bending moments)

Besides a possible inconvenient distribution of the Deadweight the overland transport on a trailer is another critical condition regarding to the strength. In that case the whole weight of the boat rests on a few points with a relatively small area. So there can be strong area forces on the hull. Those can be increased through additional impulse forces caused by bad road conditions during the overland transport. So during the transport the forces should be introduced in the hull basically through the flat keel and from the side through the transversal bulkhead. The area of the support points should be as big as possible. Due to optical and strength reasons the cross section of the pillars is relatively big and ellipses shaped.

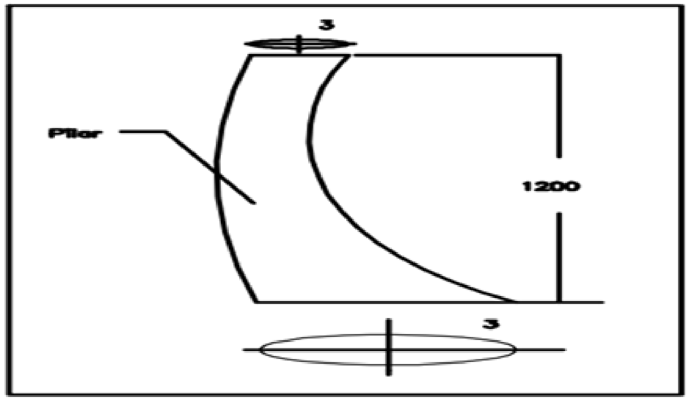

Figure 3. Cross sections of the pillar dimensions in centimeter

11. Construction Mode

The hull can be produced in a negative form or in a positive form. In which several layers of the material can be put on top of each other. If the hull is ready and separated from the negative form the two bulkheads which can be produced as one single part can be glued in the hull [7]. In the next step the deck (with the four holes for the hatches) must be glued on the hull. The pillars can be made around a positive form. When they are ready and separated from their form they can be installed on the hull. The connections between the pillars and the deck and the pillars and the roof are also glue connections. Like the hull the roof can be produced in a positive or negative form. When all composite parts are connected the solar panels can be bond on deck, roof and the four hatch covers. The montage of the four hatch covers is the next step. After that the electricity must be installed. That means the batteries and wires get assembled. (It may be favorable to install the batteries in the hull before the installation of the deck.) The last step is to install the engine.

12. Electrical Systems of the Solar Boat

12.1. Photovoltaic system

According to Solar Splash rules, sunlight is the only power source for charging energy storage devices used for propulsion of boat. The sunlight is converted to electric energy by photovoltaic array (PV) made from semiconductor materials. The energy delivered by PV arrays is stored in lead acid batteries or directly used by propulsion devices. The output power (OUT P) of PV arrays may not have a one sun output greater than 480 watts and open circuit voltage (OC V) cannot be greater than 52V [8]. Following the characteristic tests, it was concluded that the maximum power point (MPP) of PV array is at the knee of I - V curve and it is unique point. Moreover, since solar cells are semiconductor devices, the power delivered by the PV array depends on the irradiance, temperature, and load voltage (battery voltage) [8]. As these parameters always change during daytime, the current – voltage (I - V) characteristic of PV varies too. Due to this fact, if the PV is directly connected to load even at its MPP, it may not operate at its MPP. Therefore, the required power will not be obtained from PV array. By using bigger solar panel this limitation can be mitigate, but for bigger solar panel the expenditure will be higher. So to use maximum power point tracking circuit can be a smart solution of this problem. MPPT is a microcontroller based, high switching frequency, DC – DC converter that forces PV array to operate at its MPP under both changeable atmospheric conditions and load voltage situation. As battery voltage (24V) is less than PV voltage (48V), a buck (step - down) converter was used. The analog signals such as voltage, current received by control circuit of MPPT were converted to digital signal by internal analog to digital converter (ADC) of microcontroller in order to be used for MPPT algorithm. Then, according to the result of MPPT algorithm, the duty cycle of buck converter was determined to operate PV array around MPP [9]. Complete electrical diagram of the solar cell is illustrated in the following Figure 4.

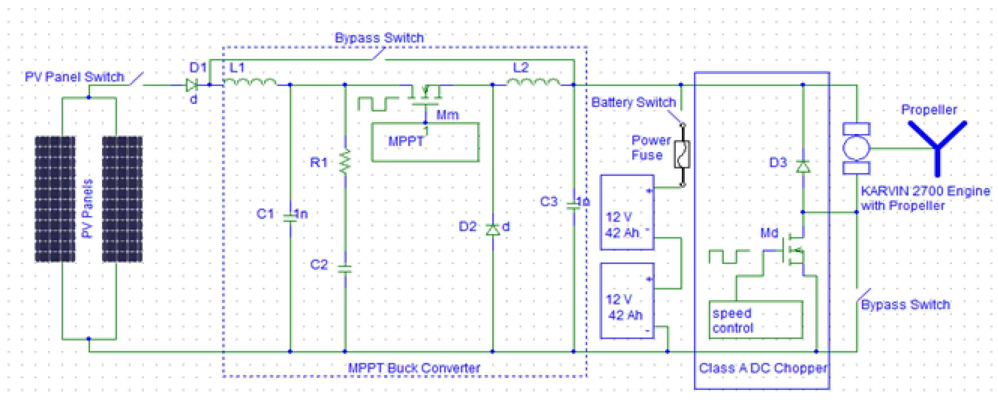

Figure 4. Electrical circuit diagram of the solar boat

12.2. MPPT design

The multipurpose control circuit was used as control circuit. A buck converter was designed for the solar boat because battery voltage was lower than the array voltage. Battery voltage was around 24V and PV array voltage was about maximum 48V. The most essential part of MPPT is its control algorithm [10]. MPPT algorithm was constructed so that it increases or decreases the duty cycle in order to determine MPP as the conditionals which change the maximum power point of PV array. Since the MPP of PV array is only one point on V - P curve, the algorithms used should operate efficiently as much as it is possible to operate the PV array at this point [10]. By considering this fact, the various algorithms were tested to determine the most efficient methods. Before testing conventional MPPT methods, the PV array was operated at its MPP by manually adjusting duty cycle of buck converter to monitor MPP points during atmospheric condition changes [11].

12.3. Motor Controller

A first- quadrant (Class A) DC chopper illustrated in fig. 5 was designed and manufactured for controlling motor speed. In this part, a constant DC voltage has to be converted into a variable DC voltage to control the speed of motor. In this type of choppers, current and voltage values of load are both positive indicating a single-quadrant operation [12]. DC choppers have several advantages like soft start, smooth speed control and high efficiency [14]. For the control part of this chopper, the same multipurpose control circuit was used. The control circuit can also be designed by the commercially available PIC microcontroller [13].

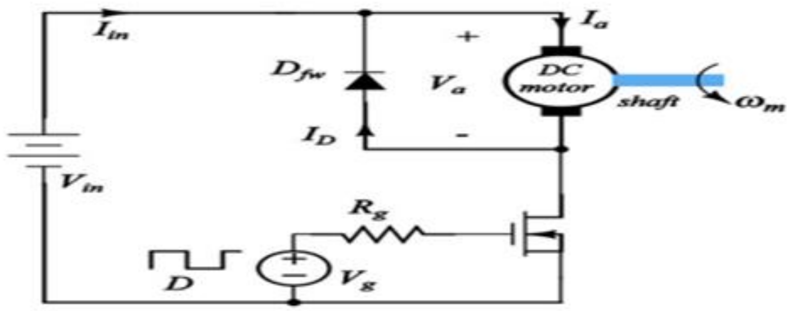

Figure 5. Class-A single quadrant DC chopper

13. Conclusion

Scientist always insists that this is the high time to minimize the dependency of fuel of conventional energy sources gradually and side by side to encourage the renewable energy sources. For this reason the use of solar energy in boat for inland navigation of developing countries can help a lot to reduce fossil fuel dependency and minimize cost. The boat is designed both electrically and mechanically for a particular weight carrier and particular distance. So if the number of passenger and distance changes then photovoltaic cell, emergency battery and engine specification should change according to the condition. Based on simple design, cost minimization, efficiency and reliability, this proposed boat can be a best option for pollution free green inland navigation system.

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