Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2017, 4(5):174-183

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Design and Construction of Solar-electric Tourboat Model

Yireobong S. Akpaba*[1], Uwemedimo R. Ebong[2], Ezenwa A. Ogbonnaya[3]

[1]Department of Marine Engineering/Naval Architecture, Faculty of Engineering, Akwa Ibom State University, IkotAkpaden, MkpatEnin, Akwa Ibom State, Nigeria.

[2]Department of Marine Engineering/Naval Architecture, Faculty of Engineering, Akwa Ibom State University, IkotAkpaden, MkpatEnin, Akwa Ibom State, Nigeria.

[3]Department of Mechanical/Marine Engineering, Faculty of Engineering, Niger Delta University, Wilberforce Island, BayelsaState, Nigeria.

Abstract Over the past few decades, the need for environment preservation consciousness and awareness has been developed worldwide. These have been done progressively and raises concern to all. In response, researchers in all disciplines are obliged to propound developments which are eco-friendly and lead towards sustainable future development. Solar energy is a prodigious renewable energy source which has enormous energy existing as heat and light, convertible into electricity. This research project is based on a modeled Solar Powered Tour Boat, code named “JJUAYS-01”.The boat is powered by the energy processed from solar by minimizing environmental pollution and fuel cost. However, for adverse weather conditions, a backup power system integrated with the photovoltaic cell drives the boat to make the system more self sustaining and reliable.

Keywords Tourism, Marine Propulsion, Model, Renewable Energy, Green-Technology

Introduction

Nowadays electric power transportation system is one of the important technologies developed in preparation for a time when the fuel source may be depleted due to the rate of usage increasing dramatically compared to its production year after year [1]. Many protected areas in the world are facing the growth of tourism pressure; the same problem is present in the areas of naturalistic interest. Tourism is seen as a viable financial option for protected areas with the tourism concessions [2].

Solar-electric boats are recommended solution for tourist navigation in areas where combustion engines are prohibited (lake, protected areas, etc.). The research into green technology for transportation, of which fully electrical powered transportation system is one of them, has to be increased and improved. For sea transportation, especially in some regions or maritime countries, it is rarely seen that research on green technology such as electrical powered ships are conducted [3]. In late 2008, the construction of the MV Auriga Leader, marked the completion of the world’s first cargo ship partially powered by solar energy. Two leading Japanese companies, the Nippon Yusen Kaisha Lines, and the Nippon Oil Corporation, jointly designed the 656-foot, 60,000-ton ship as a Toyota Motors Corporation car carrier to transport vehicles from Japan to North America. Capable of generating 40 kilowatts of electricity, the solar panels will save up to 6.5 percent of fuel used by the ship, cutting its CO_2emissions by about 1 to 2 percent or about 20 tons per year [4].

All sea transportation users are still searching for a potential of green technology to be implement in their transportation system before facing more devastating fuel crisis in the future. As such, to answer this problem, one of the green technologies that have great potential in providing an alternative to ‘fuel ships’ is by implementing the solar power system in ships/boats [5-6]. As this green technology is continuously improved upon, it will slowly reduce fuel dependency in transportation sector, furthermore it will help reduce operation cost onboard ships/boats of which fueling often constitutes the greatest percentage [7].This green technology is also noted to be eco-friendly, hence, drastically diminishing environmental (air/water) pollution arising from seaborne transportation to the barest minimum [8]. Concisely, this project aimed at propounding a method of using solar energy to power marine vessels (or watercrafts). Objectively this work focused on

- Designing a suitable system configuration for Solar–Electric Propulsion for watercrafts.
- Construction of a ship model capable of propelling electrically, powered by solar energy.

Materials and Methods

Materials

The hull material used for the construction of the model boat was mild steel plate of thickness 5mm. The main Deck was made of Plywood. The superstructure was constructed with modeling board of thickness 5mm. For strength and structural reliability, the hull was stiffed with 5mm rod of diameter.

Joints

The method of joint used for metals was welding (with electrode). For wooded joint, strong gum was used.

Surface Preparation

The power tool cleaning was used for metal surface preparation. It implies the use of power-wire brush, power grinder, and sander, for preparation of metal surface for painting by removing loose mill-scale, rust, old paints and dirt. For wooded surface preparation, emery paper (commonly called sand paper) was used.

Painting

Prior to painting, the finished welded form was filled with hardening filler to ensure complete water tightness and fine finishing. A primer was used. Afterwards, the final surface finishing was done with anti-corrosive paints.

Coating & Painting Technique

1 coat of inorganic zinc shop primer	=	10 microns
1 coat of anticorrosive	=	75 microns

Method

Powerful professional computer programmes were extensively employed throughout the project. The softwarea used were:

DELFship™: Delfship is a fully functional 3D hull form modeling program. The software also has the capacity of carrying out Hydrostatic, Hydrodynamic and Resistant Analysis. However, (Delftship 64bit Free Version 6. 27. 259. Copyright © 2006-2013 Delfship BV) was used for this project.

FREE!Ship: FREE!ship is a surface modeling program for designing ships, yatchs and boats. It also runs Hydrostatic, Hydrodynamic as well as Resistance Analysis. Precisely, (FREE!ship Version 2.3, January 2015. Copyright © 2005, M.v. Engeland) was used for this project.

HydroCompNavCad 2013 Evaluation Demo: NavCad is a computer program for the prediction and analysis of vessel speed and power performance. It also provides for the selection of suitable propulsion system components – engines, gears and propellers. However, a demo version of this program was used. Being a demo version, it has certain limitations. Precisely, (HydroComp NavCad2013 Evaluation.Buid code: 13.03.0024.NCDEMO. License: NavCad Limited Demonstration. Copyright © 1984-2013 Hydrocomp, Inc.) was used in this research work.

Hydrostatic/Hydrodynamic

Some Hydrostatic and Hydrodynamic data of the boat were computed using Delft Ship Design Software and compared with results obtained from the same computation using Free Ship Design Software, while others were obtained directly from the model. The generated results areas presented in Tables 1 and 2.

Table 1: Hydrostatics/Hydrodynamic Data Using DelfShip Design Software

Lsw	Light ship weight	0.0165 [tonnes]
Dw	Deadweight	50 [tonnes]
∇	Displaced Volume	0.005 [m^3]
P	Density of freshwater	1.000 [t/m^3]
	Density of Salt Water	1.025 [t/m^3]
Δ	Displacement	0.005 [tonnes]
LCB	Longitudinal Centre of Buoyancy	0.418m
Cb	Block coefficient	0.232
Fn	Froude number	0.403

Table 2: Hydrostatics/Hydrodynamic Data Using FreeShip Program

Lsw	Light ship weight	0.0165 [tonnes]
Dw	Deadweight	50 [tonnes]
∇	Displaced Volume	0.006 [m^3]
P	Density of freshwater	1.000 [t/m^3]
	Density of Salt Water	1.025 [t/m^3]
Δ	Displacement	0.006 [tonnes]
LCB	Longitudinal Centre of Buoyancy	0.414m
Cb	Block coefficient	0.2476
Fn	Froude number	0.403

Principal Dimensions of the Model Tour Boat

The methodology used in this project is best fitted for a scaled model ferry boat having the particulars depicted in Table 3.

Table 3: Principal Dimensions of the Scaled Model TourBoat

Variables	Description	Dimensions (m)
LOA	Length Overall	0.86
LWL	Length of Water Line	0.69
LBP	Length Between Perpendiculars	0.54
BMD	Breadth Molded	0.22
D	Depth	0.2
BWL	Beam on Waterline	0.179
T	Designed Draft	0.12

However, via components and system optimization the presented method would be perfectly suitable for large scale boats/ships. Scaling of the boat from a mother boat was carried out using the geometric and kinematic similarity laws.

Propulsion System

Components

A. Solar Panel

Monocrystalline solar panel was used. The picture of the panel is shown in Figure 1, while the particulars of the panel are shown in Table 4.

Figure 1: Photovoltaic Panel

Table 4: Solar Panel Specification

Solar Constant	1 Kw/m^2
Maximum Power (Pmax)	20W
Temperature	25 °C
Design Efficiency of Solar Panel/ Output Tolerance	20% / + 5%
Current at Pmax(Imp) / Voltage at Pmax(Vmp)	1.14A / 17.5V
Short-Circuit Current (Isc)/ Maximum Series Fuse Rating	1.28A / 3A
Open-Circuit Voltage (VOC)/ Maximum System Voltage	22.05V/DC 1000V
Surface Area of Solar Panel	0.1645m^2
Weight of solar panel	1.8KG

Monocrystalline solar cells are capable of converting 20% of the incoming solar energy into electricalenergy [9]. Aside from the quoted design power rating of the solar panel, the actual electrical power (E_{sp}) delivered by the solar panel was obtained as follows.

$$E_{sp} = I_{cs} x\ \eta_{sp} x\ A_{sp} \quad (1)$$

$$I_{cs} = 1$$

Where:

I_{cs} = Solar Constant (depends on geographical location)

η_{sp} = Design Efficiency of Solar Panel

A_{sp} = Surface Area of Solar Panel

Hence, $E_{sp} = 1 * 0.20 * 0.1645m^2$

$= 0.0329KW$

Solar energy is calculated according to the geographical position, solar panel area and solar panel efficiency [10]. For this project, solar energy data was calculated according to the solar intensity of Nigeria. Nigeria has 485.1 million MWh/day of solar energy in natural units, and an average of 6.2 hours of daily sunshine. The quantity of average solar energy in all seasons in Nigeria is 1kw per 1m^2 terrestrial surfaces.

B. Charge Controller

The system was designed to feature a solar charge controller with Maximum Power Point Tracking (MPPT) capability. Figure 2 shows the picture of the battery charge controller, while the technical specifications of the battery charge controller are presented in Table 5.

Figure 2: Battery Charge Controller

Table 5: Battery Charge Controller Specification

Parameters	Value
Nominal Voltage/ Absorption Voltage	12 V/14.4 V
Bulk Voltage / Float Voltage	14.8 V/ 13.7 V
Input Voltage Cut	11.0V - 12.2 V
Load Re-connect Voltage/ Self-Consumption	12.8 V/ 6 mA

Max PV panel Current	10A (25ºC)
Environmental Temp.	-25 ºC to 50 ºC
Total Weight	0.2 Kg

C. Battery

The model ship is designed to use one battery shown in Figure 3 with specifications of which is shown in Table 6.

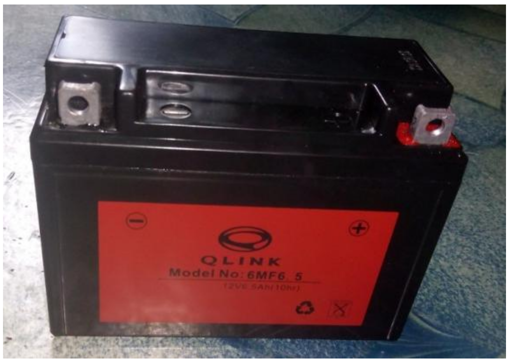

Figure 3: Battery

Table 6: Battery Specifications

Manufacturer	Voltage/Capacity [V/Ah]	Dimensions (length x breath x height) [mm]	Weight [kg]
QLINK	12/6.5	140 X 65 X 100	15Kg

D. Engine (electric motor)

AXI 2212/34 gold line Brushless Direct Current (BLDC) electric motor had been chosen for the model. The main merit of the choice is that it can operate in direct current and has flexible options to speed control. The electric motor engine is shown in Figure 4. The specifications for the motor is shown in Table 7.

Figure 4: The Electric Motor

Table 7: Electric Motor Specifications

Maximum Voltage/ Power	12V/150KW
Revolution Per Minutes (RPM)	2000
Maximum Efficiency	78%
Current Capacity	10A (60s)

E. Propeller

Theoretically, the largest diameter produces the greatest possible efficiency, so the selection of diameter is frequently determined by the available stern opening. However, in choosing propeller diameter, it is important to maintain adequate tip clearance. As a role of thump, the amount of clearance is usually somewhere between 10% to 20 of diameter [11]. Following blade area ratio trends, the fewer the blades, the greater the theoretical efficiency. In spite of the desire to provide for more blades area to control cavitation, the selection of the number of blades may occasionally be determined by other factors. The principal reason for using a different number of blades is to control noise and vibrations. The interaction of a blade passing some piece of stern structure or appendages can set up a resonant vibration and can also incite cavitation. In lieu of the above considered fact, a propeller with 3 blades; diameter 8.9" (i.e 0.23m) and pitch 8.3" (i.e 0.21m) was chosen for the tour boat model. The propeller used for the model boat is shown in Figure 5.

Figure 5: Propeller

Propulsion System Configuration

The propulsion system of the model boat is Solar-Electric. The system configuration is shown in Figure 6. For the propulsion system, the electrical circuit main voltage was 12V. The PV power terminals were connected to the Battery Charge controller in parallel. In order to prevent potentially damaging reversed currents flowing to the PV, a diode (up to 6 A maximum current) was mounted in series with the PV. The battery charge controller was connected to the battery terminal. A switch between the battery charge controller and the battery enables battery disconnection when not in use to avoid accelerated self discharge. The motor speed controller was connected in parallel with the battery and to Brushless Direct Current motor.

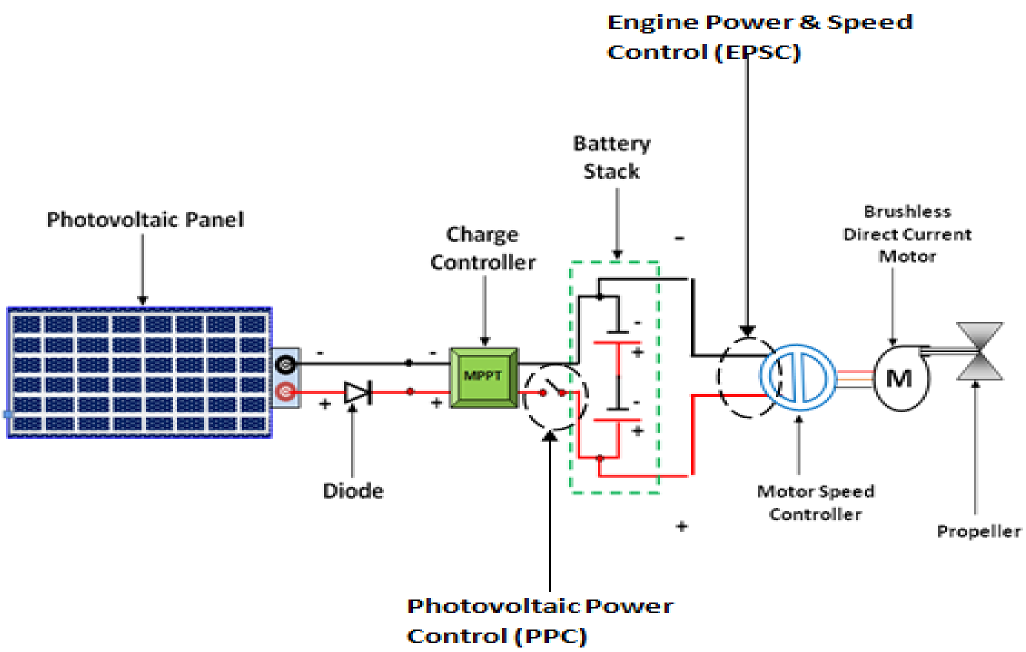

Figure 6: Propulsion System Schematic

Working Principle of the Auxiliary Electrical System

The auxiliary electrical components onboard the model tour boat consist of lighting system (4 LED bulbs) and a horn. Aboard the tour boat, the auxiliary electrical systems were powered from the 12V battery. Separate switches were connected to control the boat's horn and the lightings. The system diagram for the auxiliary is as shown in Figure 7.

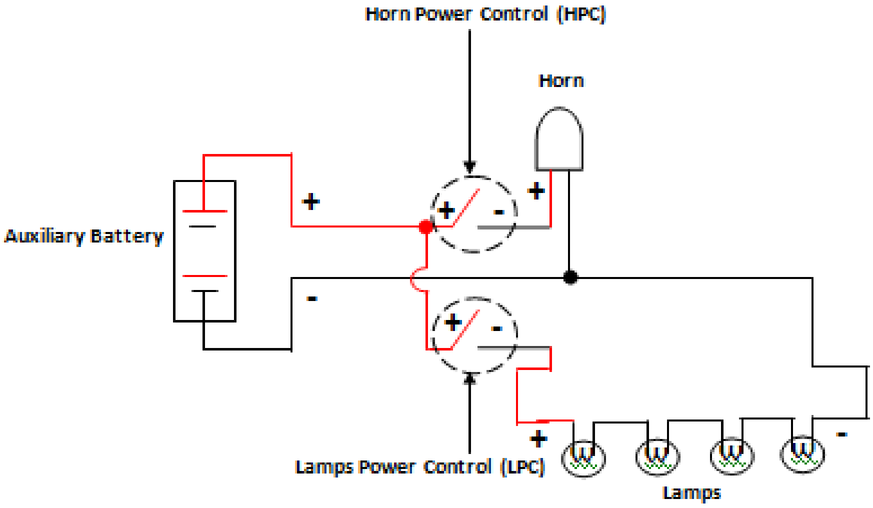

Figure 7: Auxiliary Electrical System Schematics

Control Unit

The model tour boat had as a means of control, a sizeable control unit, with control media being electrical cables. The various control points (the switch between charge controller and battery, and the engine speed controller) in the propulsion system schematic (Figure 6) and control points (the lighting switch, and the horn switch) in the electrical system for auxiliary (Figure 7) were extrapolated to their respective control points (via suitable switches) in the control board. The respective control points are as shown in Figure 8.

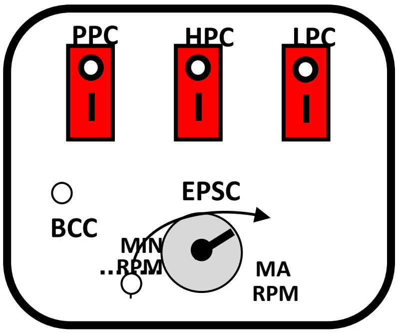

Figure 8: Control Unit

Power

Power related parameters were calculated for the tour model using the respective formula stated below.

Effective power (P_E):

This is the power required to tow the boat model without propulsion system.

$$P_E = R_T * V \tag{1}$$

Thrust (T):

$$T = K_T * \rho * n^2 * D^4 \tag{2}$$

Thrust power (P_T):

This is the power required to tow the boat model with propulsion system.

$$P_T = T * V_A \tag{3}$$

Motor Torque (Q_m):

Q_m (4)

Power Delivered at Propeller

$P_D = 2 * n * Q_m$ (5)

Efficiency

Efficiency related parameters were calculated for the tour boat model using the respective formula stated below.

Hull Efficiency (η_H):

This is expressed as the ratio of effective power to thrust power.

η_H (6)

Shafting Efficiency (η_S):

η_S (7)

Propeller Efficiency behind Ship Model (η_B):

η_B (8)

Results and Discussion

From the design analysis presented in this work, it is evidenced that solar energy can be harnessed to propel water crafts at any speed depending on the choice and power rating of the system components. Since solar energy is abundant in nature, its usage and application in nautical propulsion offers numerous merits including eco-friendliness, less vibration, high weight to power ratio, less maintenance cost etc. To successfully design and construct the solar-electric tourboat model, a sequential approach was carefully followed.

Photovoltaic (PV) Effectiveness

The actual electrical power (E_{sp}) delivered by the solar panel was noted to be 0.0329KW. Since solar radiation can be considered as “cost-free”, the charge controller guaranteed maximum absorption of photons through its MPPT capability, hence, the solar radiation was advantageously converted as much as materially possible. Prior to installing the solar panel which was earlier characterized in Table 4, it was tested with varying loads connected across. The result showed that the power output of the solar panel depends on the resistance of the electrical load to which it is connected. In an open circuit situation (infinite resistance) the voltage of the solar panel was high, but no current flowed and therefore no power was generated. In short circuit situation (zero resistance), current flowed but with zero voltage and so again no power was generated. These results all follow from Ohm's Law which gives the relationships between voltages, currents, resistances, and powers. Figure9shows the curve of typical PV panels. The mid-point of the curve denotes the operating point for the PV. This simply shows the point at which the solar panel generates its peak power output. Since power is a product of voltage and current, the rectangle with the largest area which can be drawn under the plotted curve has its upper right hand corner at the operating point. Usually, it is impossible to fit a rectangle with a larger area under the curve.

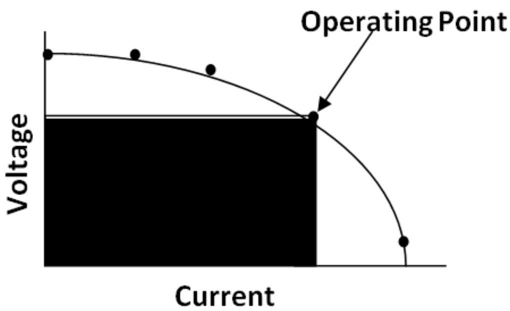

Figure 9: Photovoltaic Panel Characteristic Curve and Typical Operating Point

The solar panel used onboard the tour boat model had efficiency of 20%, rated output of 20watt and an area of 0.1645m^2. Hence, the peak output power of the panel was 32.9Watts.The panel was also tested for output power in a flat position and when tilted to angle 45^0. It was evidenced that the panel receives more photons at tilted angles of about 45^0 - 50^0. Hence, the PV panel was installed tilted at an angle of 45^0.

Charging Effectiveness

The manufacturer's data for voltage thresholds of the charge controller was verified as well as determining the current intensities in function of the battery state of charge. Obviously it was evidenced that the output voltage is dependent on the input. The output can never outrange the input. Thus, the input voltage must always be at least equal to the output voltage to allow the battery charge regulator to work according to its specifications. Following a full charge and self-discharge of the battery at specific time intervals, it was observed that a deep discharge of battery can be drained up to state of charge of 0.4.

Propulsive Effectiveness

The electric motor was tested with tachometer for its rated RPM. The resulted RPM was observed to be 1450 RPM, as against 1400RPM quoted by manufacturers. However, this was considered advantageous. The voltage rating of 12V was observed to be true. A combine consideration of the electric propulsion system components matching were considered appropriate. This was because with the solar panel of 17.5V, the battery delivering 12V and the electric motor rated 12V, the photovoltaic panel could comfortably give the battery 14V (based on the optimization by the charge controller) and the battery could as well discharge 12V to the motor. The panel still had about 3.6V to itself which was considered factor of safety. The battery on the other hand had 2V to itself which was also its factor of safety. The factor of safety had to be there to avoid complete drainage of the device.

Conclusion and Recommendations

Conclusion

The design and construction of a solar-electric tour boat for tourists' transport along the coast, in the rivers, in the lakes and in navigating restricted areas has been presented. In lieu of the global demand for green technology, it is no gain saying that solar-electric boat propulsion is an effective means of helping to achieve ecosystem preservation, reduction of CO_2, $NO_2$and SO_2emission, etc. This research project therefore presents a model for zero pollution system of nautical navigation.

Recommendations

In lieu of the need for continues research and development in this area of nautical propulsion, the following are recommended.

- Future design should incorporate simulation to analyze and understudy the relative performances of the various components to achieve optimized design outputs.
- Incorporating fuel cell to achieve a hybrid propulsion system is also highly recommended for future designs. That would expand the operation capacity of the vessel.

Acknowledgement

We acknowledge the Department of Marine Engineering/Naval Architecture, Faculty of Engineering, Akwa Ibom State University for creating an enabling environment. The Department granting access to her Ship Design Laboratory, which aided the success of the work.

References

[1]. Hochkirch, K. and Bertram, V. (2010) "Options for Fuel Saving for Ships," *Mare Forum* 2010: *Maritime Transportation of Energy*, Houston.

[2]. Giuseppe, S., Donato P., Andrea M. & Giuseppe M. (2012). Solar-Electric Boat. *Journal of Transportation Technologies*, 2:144-149.

[3]. John, G., Newmann, S. (2011). Marine Applications of Solar Technology. *Solar Bulletin*, pp. 11-12.

[4]. Toyota Motor Sales, U.S.A., Inc. Toyota's Solar-Powered Cargo Ship. *Toyota.* [Online] 8 2, 2010.http://www.toyota.com/esq/articles/2010/Solar_Powered_Cargo_Ship.html.

[5]. Samuel, A., Rosca, P. (2009) Review of Solar Boats. [Online Serial] Available: http://www.solarboatcpmpetitions.com [Accessed: 2016, 2016, Feb. 12].

[6]. Yoshifumi, G. (2010). Alternative Sources of Energy in Shipping. *Journal of Navigation*, 63(1-2): 435-448.

[7]. Morehouse J, (2008). "Overview of The ASME "Solar Splash": The intercollegiate World Championship of Solar/Electric Boating", ANES-ASME.

[8]. Sanyo, D. (2005). Institution of Electrical and Electronics Engineers, Electric Ship Technologies Symposium, *ESTS*, Norway. pp. 6-7.

[9]. Mahmud, K., Morsalin S., & Khan M. (2014). Design and Fabrication of an Automated Solar Boat. *International Journal of Advanced Science and Technology* 64(6):31-42.

[10]. Leiner, R. (2007). Research solar power boat-data management and online visualization, IEEE, *AFRICON*, pp. 1-5.

[11]. Noosomton, J. & Charoensuk, J. (2015). The New Propeller Design 3 Blades Type on 18^{o} Skew Angle and Testing Cavitation of Tailing Thai Boat. *International Journal of Engineering Research,* 4(5): 257-263.