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Implementation Of An Electric Boat Designed To Operate On Frequent Short Trips

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Abstract

An interesting and viable means of electric transport is the use of electric boats for short trips in harbour areas or inlet seas. The use of such a means of transport can reduce the road traffic in busy areas and can also be used as a tourist attraction. Over the last two years the department of Industrial Electrical Power Conversion, in the Faculty of Engineering at the University of Malta has been involved in the design and building of a prototype seven-seater boat. The principal aim of this project is to use this electric boat to replace an existing tourist boat trip, which is presently run using IC engines. This 2.1 km long trip is used to view the "Blue Grotto Caves" which form part of the Maltese heritage and a very important tourist attraction, making their conservation of utmost importance. This paper will explain the technique involved and hardware required in building this prototype. A briefing of the methodology used in Matlab simulations will be also presented. The practical results obtained will be shown, highlighting as well the hardware modifications done to gain efficiency and usability of the whole system design.

Keywords: Boat, Battery, Simulation, Modelling, Emission

1 Introduction

The caves of the Blue Grotto form part of the Maltese heritage and a very important tourist attraction, making their conservation of utmost importance. These caves can be reached by private boats or by organized boat trips, like those available from a nearby inlet sea, called "Wied iz-Zurrieq" (*shown in Figure 1*). As can be seen in figure 3, this boat trip is 2.1 km long. The service is at present offered on traditional Maltese boats powered by internal combustion engines, cruising at a maximum speed of 5 to 6 knots to allow the visitors admire the beautiful scenery present on the south-west of the island.

Figure 1: Blue Grotto

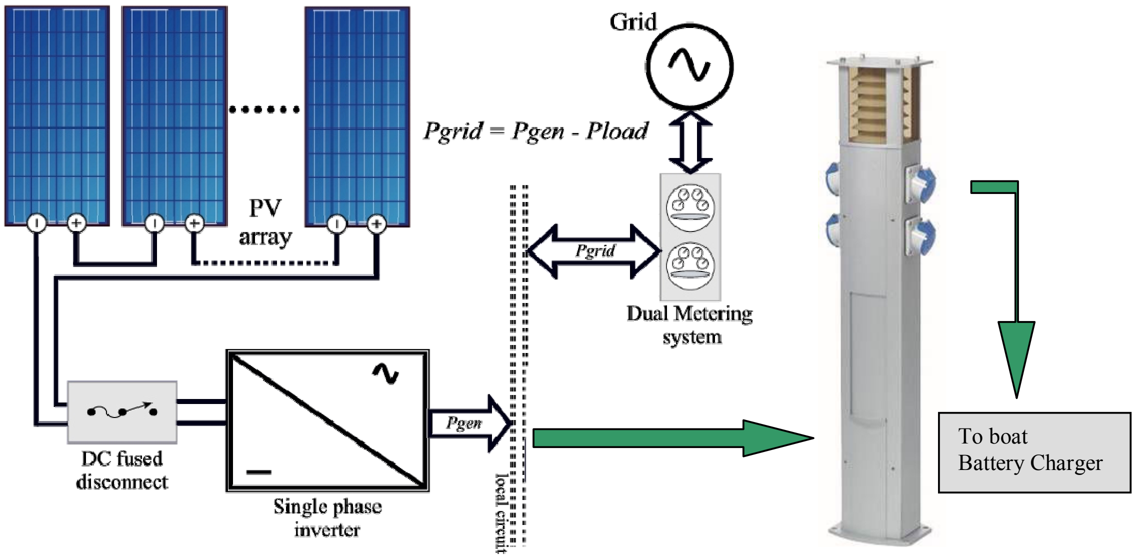

Figure 2: Suggesting a system of solar panels installed near the mooring pontoons of the trip boats

Nowadays people are becoming more sensitive on environmental issues. An electrically propelled boat would not pollute the environment and would attract more tourists willing to take a trip that is pollution-free. Electric propulsion for visiting the place in question would also offer various advantages over the currently fuel run engines. In sea caves, noise is amplified due to reflections. Fuel engines are certainly more noisy than electric systems, hence causing a discomfort for the tourist and also to the guide throughout his explanation. Fuel exhaust smell is also eliminated.

Figure 3: Showing the 2.1 km trip

Electric propulsion provides much better speed control allowing better maneuverability of the boat than fuel engines. Apart from the added comfort during the trip, boat electric propulsion can contribute also to the usage of *green energy*, especially if the system is designed as proposed in this paper. Figure 2 suggests the use of a grid connected PV system to feed in the energy that is used to charge the motive batteries which power the boat. Employing a system like this would also eliminate the emissions from the generation of electricity required to charge the boats. The photovoltaic panels can also be used to provide shelter from the blazing sun while visitors wait for their trip. The technical details of the simulation and the practical setup will be considered in the next sections.

2 Simulation Model Setup Used

In order to be able to predict the performance of the boat, the whole system was designed mathematically using *Matlab Simulink*[R] . The model used here is based on the differential equations of a d.c drive although other drive systems can also be used by replacing the electrical torque equation with the appropriate one. The technical parameters of the motor, gear-box, propeller and boat used, were experimentally achieved to obtain the craft's velocity against voltage and current applied to the motor. In obtaining the required parameters and numerical coefficients for the model, various traditional methods and empirical graphs were used. Figure 4 shows a simplified version of the model implemented in Matlab.

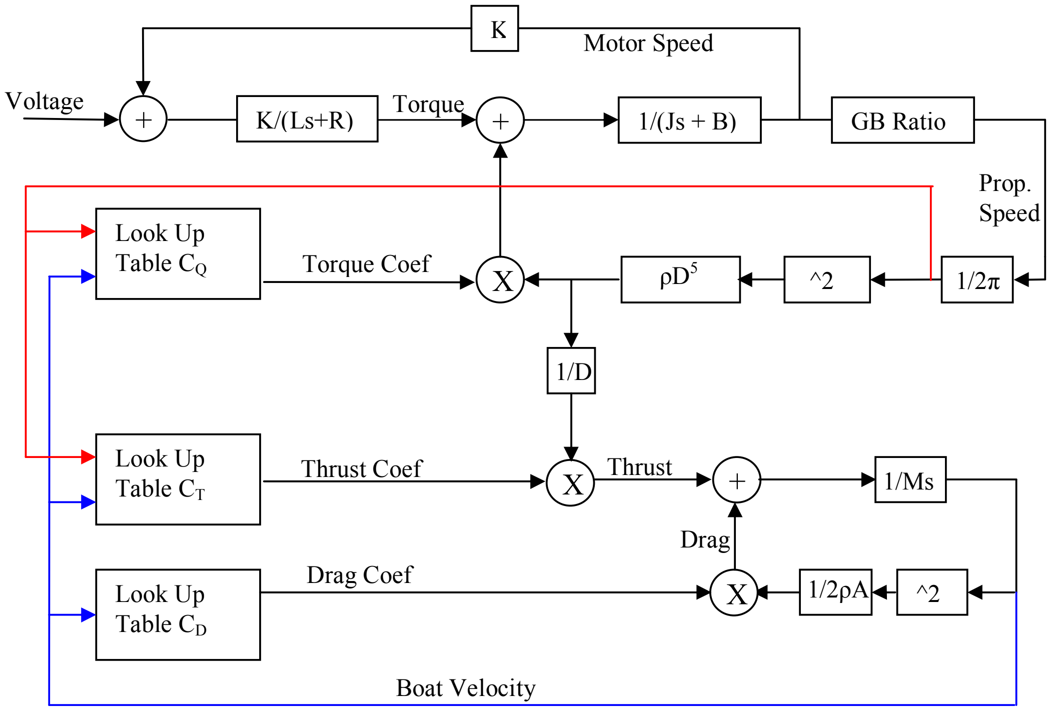

Figure 4: Simulation diagram

The majority of the work was dedicated to model the boat's drag and thrust as accurately as possible. The base equation used to calculate the torque developed by the propeller, is given by:

$$Q = C_Q p\, n^2 D^5 \qquad (1)$$

Where:

Q is the torque
C_Q is the torque coefficient
n is the speed of the propeller in revs per second
D is the diameter of the propeller
p is the density of the medium the propeller is working in .

This equation links mathematically the electrical torque produced by the motor, given by :

$$T = KI \qquad (2)$$

Where:

T is the torque produced by the motor
K is the motor constant given in volts/rads^{-1}
I *is* the stator current

to the mechanical torque developed. Therefore this is the equation used in the closed loop simulation to observe the steady state readings at various motor input voltages. The torque coefficient C_Q mentioned in equation (1) depends on the advance ratio J which is given equal to:

$$J = V/nD \qquad (3)$$

Where V is the velocity of the craft, which in turn depends on the thrust developed by the rotating propeller less the drag acting on the boat while in motion. The velocity of the craft is referred to a look up table holding a set of values for the particular propeller used on the prototype boat. (Figure 5).

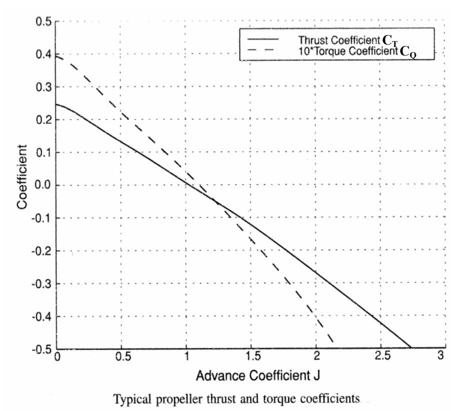

Figure 5: $C_{Q,}\, C_T$ Values of Propellor

The equation to calculate the thrust is given by:

$$F = C_T p\, n^2 D^4, \qquad (4)$$

where

C_T is the thrust coefficient

and the drag equation employed is :

$$F_d = ½\, C_D\, A\, p\, v^2 \quad (5)$$

where:
C_D is the drag coefficient
A is the total wetted surface area of the boat
v is the boat's velocity in m/s

These two equation (4, 5) were used to calculate the boat's velocity, by applying Newton's second law, namely $F=ma$. The coefficients C_T and C_D are also dependent on the boats velocity. C_T is again particular to the propeller used on the boat, and in fact is obtained from a similar graph like the one shown in Figure 5. C_D is a constant particular to the boats hull shape and depends on two other important constants namely Reynold's number and Froude's number. For the hull of the mentioned boat Reynold's number is a constant while Froude's number varies according to:

$$N_F = v / (L.g)^{1/2} \quad (6)$$

where:
N_F is froude's number
L is the hull's waterline length
g is the gravitational pull

Froude's number is directed to a look up table whose values are obtained from the graphical representation shown in figure 6, which in turn outputs the required drag coefficient, including also Reynold's constant. The no bow bulb line values were used.

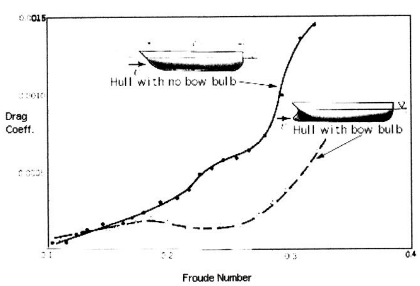

Figure 6: Drag Coeff.

3 Boat Setup

The boat that was used is shown in Fig 7. This is the same type of boat shown in figure 1 and therefore the one used at Blue grotto. An electric outboard motor which is efficient and uses the latest state of the art technology was used. The motor shown in fig.8 was fed from four 6V 180Ahr Gel type batteries through a control unit which incorporates the necessary control circuitry and a battery Management unit with a Bluetooth transceiver.

Figure 7: Drag Coeff.

The specifications of the boat shown in figure 7 are listed hereunder:

Boat
length : 15 feet
approx. weight : 300kg

Battery Management Unit
200 Amp shunt current
Center and full voltage

Battery Pack
4sealed lead acid deep cycle cells
6V 180Ah each
total weight : 130 kg

Charger
24V
35Amps

Electric Outboard
Weight : 25 Kg
Voltage : 24V
Maximum Input Power : 2Kw
Maximum Propeller speed : 1020 R.P.M
Overall efficiency : 45%

Figure 8: Torqeedo Outboard

4 Tests and Results Obtained

Through the use of the BMU from Best Abertax the boat described above was taken out at sea to carry out various tests. The conditions and measurements of one particular test are shown hereunder.

Persons on board : 6
Trip time : 60 minutes
Distance covered: 7.1Km
Battery initial state of charge : 100%
Battery final state of charge : 73%
Total Ah Discharge : 47.6
Total energy used : 1.16 KWh
Voltage per cell at start-up : 2.19V/cell
Voltage per cell at end of trip : 2.1V/cell
Full throttle max. current recorded : 83Amps
Full throttle max. speed recorded : 9.3Km/hr (5 knots)

The BMU was vital to gather the necessary Battery information and hence plot the results for analyzes and comparison with the simulation results. The most interesting result (shown in figure 9) is a plot of the current from the batteries against the speed. Due to the type of boat hull one can notice that there was a linear increase in the speed with the current but this levelled off and there was hardly any change in speed with the current increasing from 50 to 80 Amps. Therefore limiting the power of the motor for this hull is a must in order to ensure the optimum range and performance.

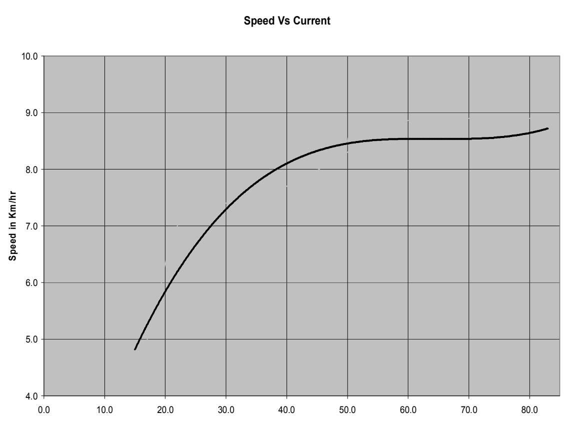

Figure 9: Speed Vs. Current curve

Figure 11 below shows the current, Amphour, and state of charge, while figure 10 is a plot of cell voltage and energy (kWh) consumed from the batteries. During the 1 hour drive with the help of the BMU current indicator an average current of 50Amps could be maintained through careful control of the throttle. This can be easily seen from the Amp hour curve which logged 50Ah after the test drive. Multiplying the 50A by an average battery voltage of 25V gives us 1.25kWh which is the energy consumed in this test. This is quite interesting when one considers that at the moment to achieve the required performance the same boats are usually equipped with an 8 horsepower 4 stroke engine (8 x 746W = 5.97kW).

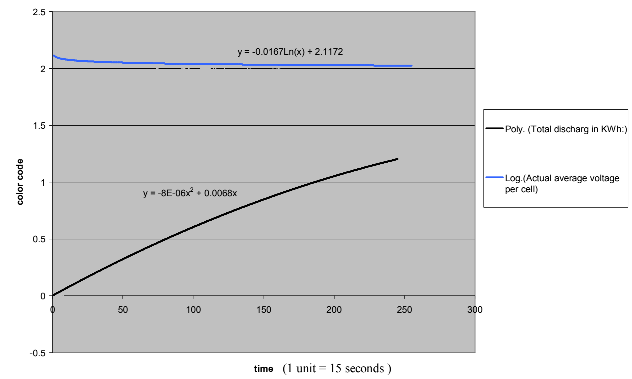

Figure 10: Voltage,energy time curves

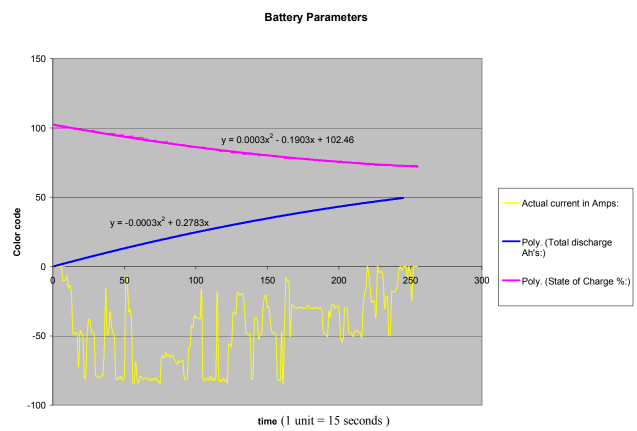

Figure 11: SOC, Current, AH time curves

5 Complete Project Proposal

For the purpose of the Blue Grotto tour, a fleet of five to seven boats would serve the task. The idea is to have four to five boats on the route, while the rest are tied to the pontoon having their batteries being charged. Different ways of communication with the boats' installed BMU (battery management unit) exists. The simplest is through the use of an RS232 or USB cable. However experience has shown that this is cumbersome and the person interested in the information is reluctant to go around connecting his laptop or palm reader to the boat. Infrared is also possible but this does not present too much advantages to the use of a cable as it has a very limited range. Bluetooth and Zigbee communication are becoming more commonly used with Bluetooth picking up much more due its widespread use in equipment The use of GPRS is also very attractive especially if the battery is monitored via the internet. Apart from battery parameters, the same communication channel can be used to provide positioning information of the each boat. This can be accomplished by using a GPS system**.** A Webserver has already been set up with a database which holds all the data of all BMU's installed on the boats. The BMU and the GPS will both transmit their data via Bluetooth to the GPRS unit. This data is then transferred to the Webserver by programming the GPRS unit which connects automatically to the GPRS internet point, obtains an IP address and then opens a TCP/IP link over GPRS and transfers data. Thereafter all this electronic information is stored on the webserver and viewed by the ticket booking office to plan efficiently the boats' daily trips. The department of Industrial Electrical Power Conversion at the Univ. of Malta together with Best Abertax Ltd. is currently involved in testing the wireless communication system A block diagram of the proposed system is shown in figure 12.

6 Future Improvements

The department of Industrial Electrical Power Conversion at the Univ. of Malta.is currently carrying out research work on a new generation of **motive power** Lithium Ion batteries. The use of these batteries for longer trips will be investigated and hopefully the outcome will be reported in the next EVS conference.

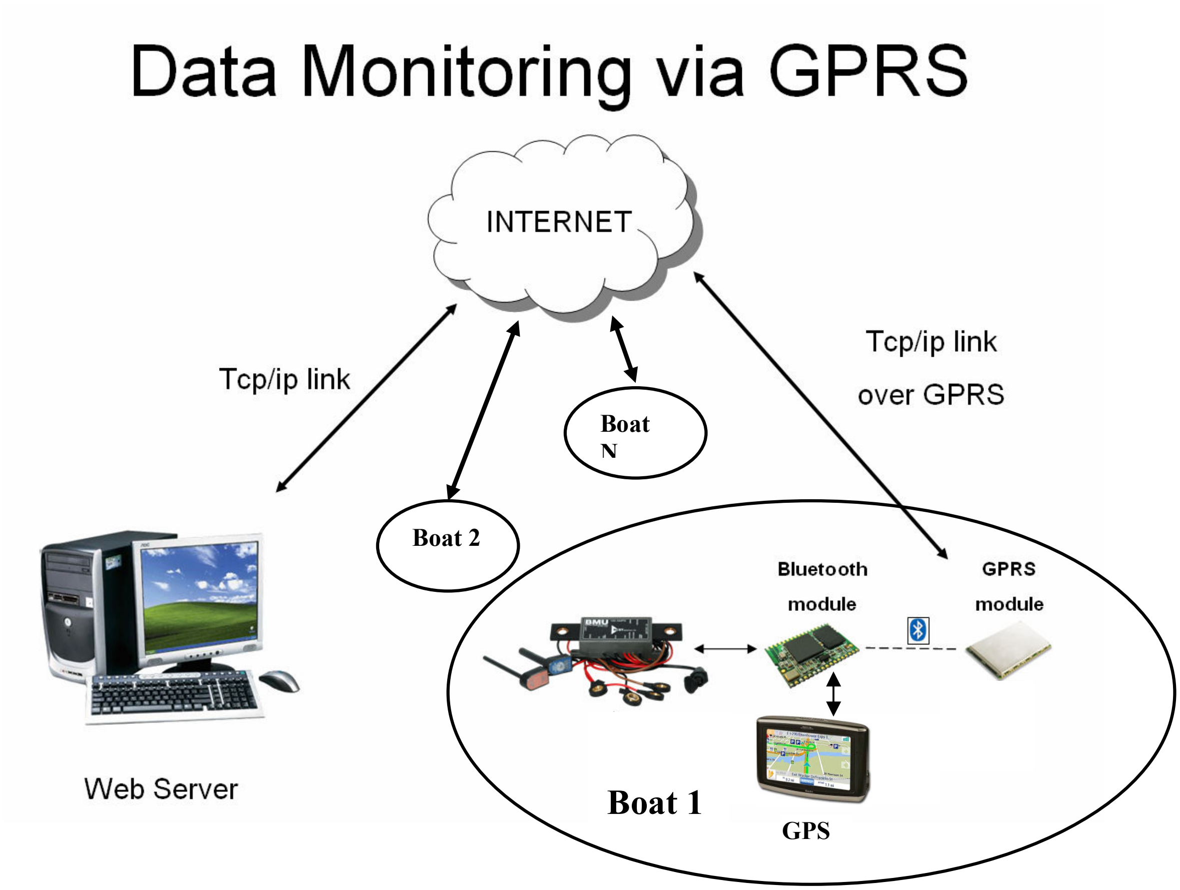

Figure 12: System Layout

Acknowledgments

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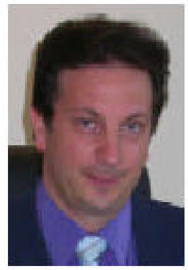

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