VOL. 10, NO. 18, OCTOBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

# POWERTRAIN MAIN COMPONENTS SIZING OF PHERB USING KL RIVER DRIVING CYCLE

J. S. Norbakyah, W. H. Atiq and A. R. Salisa
School of Ocean Engineering, Universiti Malaysia Terengganu, Kuala Terengganu, Terengganu, Malaysia
E-Mail: salisa@umt.edu.my

## ABSTRACT

Due to clean and efficient power generation, the plug-in hybrid vehicle has received extensive attention. A series-parallel plug-in hybrid electric recreational boat (PHERB) is a new model for recreation boat innovation was introduced. In this paper, a design of main components sizing for a series-parallel PHERB powertrain was presented. The PHERB powertrain component sizing begins with calculation of boat energy and power requirements for typical driving conditions according to the boat power parameters, specifications and performance requirements. The size and capacity of the main components are determined through a power flow analysis so as to fulfill the PHERB powertrain design specifications and requirements. After that, the parameters and specifications for each component that make up the overall structure of the PHERB powertrain are defined based on the developed Kampung Laut river drive cycle. The results obtained from this analysis are within reasonable range and satisfactory.

**Keywords:** PHERB, driving cycle, powertrain, modeling, power requirement.

## INTRODUCTION

In globalization era, the major challenges is the planet global warming, by limiting or even reducing the emissions of greenhouse effect gases and notably the carbon dioxide ($CO_2$) emissions (Le Berr *et al.* 2012). Emissions related to boat propulsion, which are $CO_2$, sulfue oxides ($SO_x$), and nitrogen oxides ($NO_x$) have a significant responsibility for environmental problems such as the greenhouse effect, acid rain and air pollution (Han *et al.* 2014). Boats are designed for recreative, fishing and surveillance purposes, however in tropical undeveloped countries boats are employed for different applications such as passenger and goods transportation fairly away from nominal power engine, which lies from 8 to 12 % engine efficiency (Corredor *et al.* 2012). As solution, PHERB is a series-parallel plug-in hybrid electric recreational boat was introduced. Every vehicle has a own powertrain. A powertrain is a system of mechanical parts in a vehicle that first produces energy, then converts it in order to propel it, whether it be an automobile, boat or other machinery. Powertrain is the vetail part before the modelling and simulation of vehicle because to achieve good fuel economy, performance and driveability.

The PHERB powertrain has only one electric machine (EM) to function as either an electric generator or motor in different time intervals specified by a special developed energy management strategy that control the power flow according to desired operating mode. The PHERB uses a hybrid energy storage system (ESS) combining batteries and ultracapacitors, which can work together effectively to improve drive performance and energy efficiency. Subsequently the size of the internal combustion engine (ICE) can be reduced since it is operated during certain operation mode only. Figure-1 shows a schematic illustration of the proposed series-parallel PHERB powertrain.

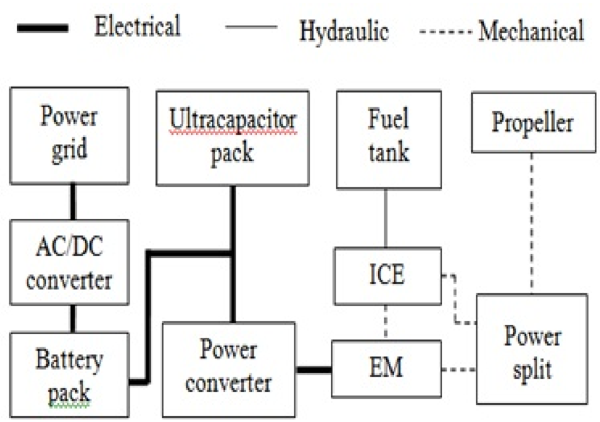


**Figure-1.** Schematic illustration of series-parallel PHERB powertrain.

## PHERB PARAMETERS, SPECIFICATIONS AND REQUIREMENTS

Design specifications, requirements, sizing and selection for EM, ICE and ESS are carried out, in order to identify the main components of PHERB powertrain. The EM, ICE and ESS are sized according to boat parameter, specifications and performance requirements listed in Table-1, based on the boat power requirement for steady state velocity using dynamic equation boat.

All the data from Table-1 are used to calculate power requirement. The power required, $P_{req}$ for a boat as shown in Figure-2 is calculated using equation (1) where $P_E$ is an effective power and $\eta_T$ is the total propulsive eficiencies (Minami *et al.* 2013 and Minami *et al.* 2010)

$$P_{req} = P_E \times \eta_T \quad (1)$$

After the sizing process, main components are selected based on the parameters and specifications.

VOL. 10, NO. 18, OCTOBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

**Table-1.** PHERB parameters, specifications and performance requirements.

| Parameter and Specifications | |
|---|---|
| Configuration | Series-Parallel |
| Length overall, L | 12.4 m |
| Length at waterline, LWT | 11.0 m |
| Breath, B | 1.8 m |
| Draught, T | 0.64 m |
| Length between perpendicular, LPP | 10.67 m |
| Density of water, ρ | 1000 kgm$^{-3}$ |
| Total propulsive efficiencies, ηT | 0.9 |
| **Performance Requirement** | |
| Maximum speed | Over 30 km/h |
| EV range | 10 km |

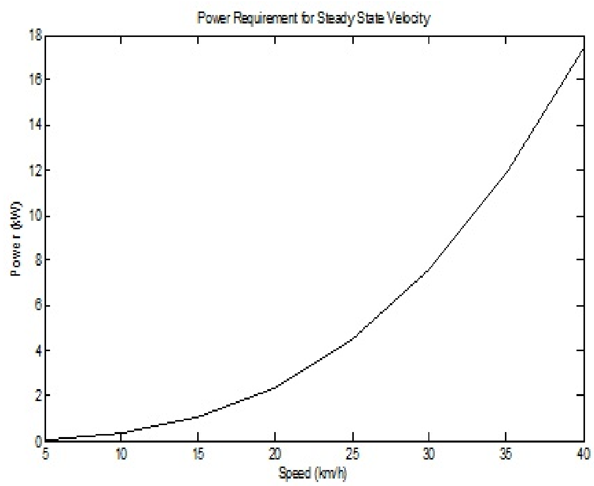


**Figure-2.** Boat power requirements for steady state velocity (Norbakyah *et al.* 2015).

## MAIN COMPONENTS SIZING

Based on the boat power requirements for steady state velocity, the main components of the PHERB powertrain were sized.

### Electric machine

The power requirement of the electric propulsion motor is determined by the maximum speed. The designed maximum speed is assumed as 40 km/h. All calculations are undertaken with maximum mass. To achieve 40 km/h, the propulsion motor power requirement is:

$P_{EM}$ (40 km/h) = 17.4 kW

Motor size and cost may be reduced if the speed demand is relaxed. If the boat is designed to run at 35 km/h it will still meet the requirements, but allowing for a smaller propulsion motor:

$P_{EM}$, continuous = $P_{EM}$ (35 km/h) = 11.8 kW

### Internal combustion engine

The ICE requirements are determined by the average power requirements in the series PHERB powertrain concept. Cruising at 30 km/h, the maximum velocity is assumed to define the average power in the worst case scenario. The continuous ICE output power requirement is:

$P_{ICE}$, continuous = $P_{EM}$ (30 km/h) = 7.6 kW

The electric output power is 8 kW with an estimated efficiency of 85 %, the mechanical input power has to be 10 kW. This is the minimum continuous ICE power requirement:

$P_{ICE}$, continuous = 10 kW

### Energy storage system

There are two main energy storage requirements, which are an available energy and a maximum power. The available energy should be sufficient for 10 km in pure electric driving mode. The average velocity is about 10 km/h. In a simplified calculation, an average of 10 km/h is assumed. This is to take into account that the average speed is based on a higher speed plateau but with frequent starts and stops. The motor power to propel the boat at 10 km/h is:

$P_{EM}$ (10 km/h) = 0.4 kW

Assuming an overall drivetrain efficiency of about 60 %, the required battery storage capacity is at least:

$E_{ESS}$, min (10 km / 10 km/h) x (0.4 kW / 0.6) = 0.7 kWh

The battery power should be sufficient to boost the propulsion motor to its highest power. Maximum motor power is 1.5 times continuous motor power.

$P_{ESS}$, max = 1.5 x $P_{EM}$, continuous – $P_{ICE}$, continuous
= 6 kW

In order to achieve full performance, a maximum discharge of 3C (3 times the rated capacity) was assumed. The battery storage capacity is determined by the requirement, provided it also meets the criteria for pure electric range

$E_{ESS}$ = $P_{ESS}$, max / 3 x h = 2 kWh

### Selected components parameters and specifications

Table-2 lists the estimated main components of PHERB powertrain, which are EM, ICE and ESS based on each component specifications and requirements during the sizing process.

VOL. 10, NO. 18, OCTOBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

**Table-2.** Main components of the PHERB powertrain for steady state velocity.

| Component | Specifications |
|---|---|
| ICE | 20 kW @ 3000 rpm |
| EM | 30 kW AC induction motor |
| ESS | Li, 5 kWh, 6 Ah |

**RESULTS AND DISCUSSIONS**

The analysis on the influence of actual developed driving cycle on the individual components that make up the overall structure is carried on the PHERB powertrain using KL river driving cycle. The route of KL driving cycle is shown in Figure-3.

As shown in Figure-4, the drive cycle lasts for 1360 s covering a distance of 1.27 km with an average speed of 9.34 km/h and maximum speed of 34 km/h. Based on the PHERB power requirement as illustrated in Figure-5, the components sizing for KL river driving cycle are listed in Table-3.


**Figure-3.** The KL river route map.

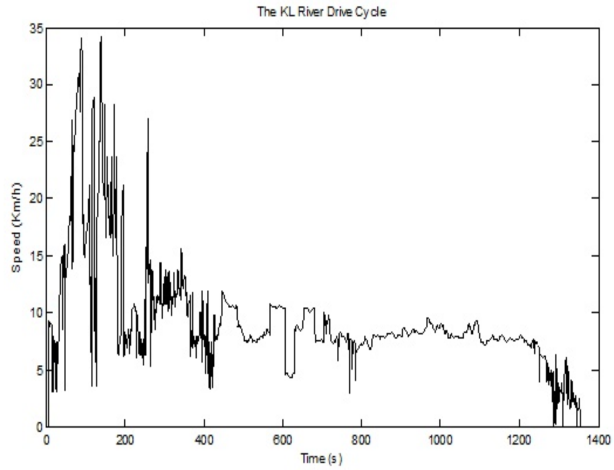


**Figure-4.** The KL river driving cycle.

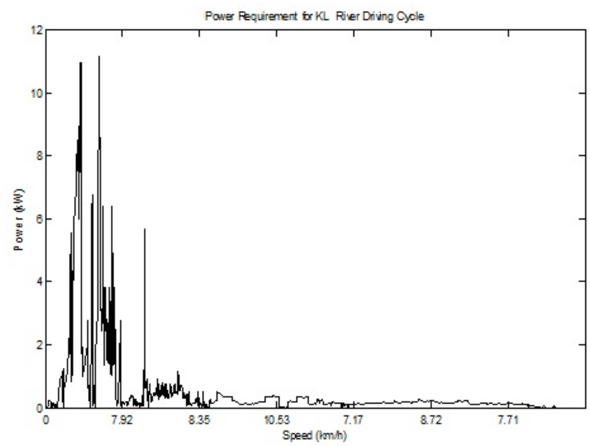


**Figure-5.** Boat power requirements for KL river driving cycle.

**Table-3.** Components sizing for KL river driving cycle.

| EM | |
|---|---|
| $P_{EM}$ (34 km/h) | 10.96 kW |
| $P_{EM}$, continuous = $P_{EM}$ (30 km/h) | 7.61 kW |
| **ICE** | |
| $P_{ICE}$, continuous = $P_{EM}$ (25 km/h) | 4.50 kW |
| $P_{ICE}$, continuous | 5.00 kW |
| **ESS** | |
| $P_{EM}$ (20 km/h) | 2.46 kW |
| $E_{ESS}$, min | 4.10 kWh |
| $P_{ESS}$, max | 4.67 kW |
| $E_{ESS}$ | 1.56 kWh |

**CONCLUSIONS**

The results of the component sizing for KL river driving cycle, in terms of power and capacity for EM, ICE and ESS are within reasonable and expected range. It can be concluded that the individual components that make up the overall structure of the PHERB powertrain using KL river driving cycle are correct.

## ACKNOWLEDGEMENTS

The financial support of this work by the Fundamental Research Grant Scheme and the Universiti Malaysia Terengganu, is gratefully acknowledged.

## REFERENCES

[1] Corredor L., Baracaldo L., Jaramillo L., Gutiérrez J., and Jiménez D. (2012). A comprehensive energy analysis of a hybrid motorization for small/medium boats. International Conference on Renewable Energies and Power Quality (ICREPQ'12) Santiago de Compostela, Spain.

[2] Han J., Charpentier J. and Tang T. 2014. An Energy Management System of a Fuel Cell/Battery Hybrid Boat. Energies, 7, pp. 2799-2820; doi:10.3390/en7052799.

[3] Le Berr F., Abdelli A., Postariu D. M. and Benlamine R. 2012. Design and Optimization of Future Hybrid and Electric Propulsion Systems: An Advanced Tool Integrated in a Complete Workflow to Study Electric Devices. Oil & Gas Science and Technology – Rev. IFP Energies nouvelles, Vol. 67, No. 4, pp. 547-56.

[4] Minami S., Hanada T., Matsuda N., Ishizu K., Nishi J. and Fujiwara J. 2013. Performance of a Newly Developed Plug-in Hybrid Boat. Journal of Asian Electric Vehicles, Vol. 11, No. 2, pp. 1653.

[5] Minami S., Hanada T., Matsuda N., Ishizu K., Nishi J. and Fujiwara J. 2010. A Newly Developed Plug-in Hybrid Electric Boat (PHEB). Journal of Asian Electric Vehicles., Vol. 8, No. 1, pp.1383-1392.

[6] Norbakyah J. S., Atiq W. H. and Salisa A. R. 2015. Components Sizing for PHERB Powertrain using ST River Driving Cycle. IEEE International Conference on Computer, Communication, and Control Technology (I4CT 2015), Kuching, Sarawak, Malaysia.