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A CONCEPTUAL DESIGN OF MAIN COMPONENTS SIZING FOR PHERB POWERTRAIN

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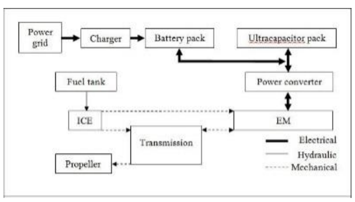
Graphical abstract



Abstract

A conceptual design of main components sizing for series-parallel Plug-in Hybrid Electric Recreational Boats (PHERB) powertrain is introduced in this paper. The PHERB powertrain has only one electric machine to function as either an electric generator or motor in different time intervals specified by a special developed energy storage strategy that control the power flow according to desired operating mode. The PHERB uses a hybrid energy storage system combining batteries and ultra-capacitors, which can work together effectively to improve drive performance and energy efficiency. Subsequently the size of the internal combustion engine can be reduced since it is operated during certain operation mode only. 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 Kuala Terengganu river drive cycle. The results obtained from this analysis are within reasonable range and satisfactory.

Keywords: Component sizing, PHERB, power requirement, drive cycle

1.0 INTRODUCTION

As the concern for oil depletion, global warming, fuel economy and emissions standards have attracted society's attention to alternative vehicles. New types of clean and energy efficient powertrains are urgently needed in order to boost the fuel economy, increase the all electric range (AER), and at the same time mitigate the harmful emissions.

This paper presents a conceptual design of main components sizing for Plug-in Hybrid Electric Recreational Boats (PHERB). Figure 1 shows a schematic illustration of the proposed series-parallel PHERB powertrain. In the PHERB powertrain, the main power source to drive the boat is the electric machine (EM). The primary energy source of the EM is the battery pack to supply continuous power to the boat and the secondary energy source is the ultra-capacitor pack which is used to absorb the power pulses during regenerative braking and deliver power for peak acceleration. The internal combustion engine (ICE) is set as a backup power source. It is only operated under certain conditions and will not be on all the time in order to minimize the fuel consumption and harmful emissions. The size of the ICE can be reduced since its power is needed only when the battery state of charge (SOC) level is low and to provide required extra torque to assist the EM in order to operate the boat during high torque drive condition.

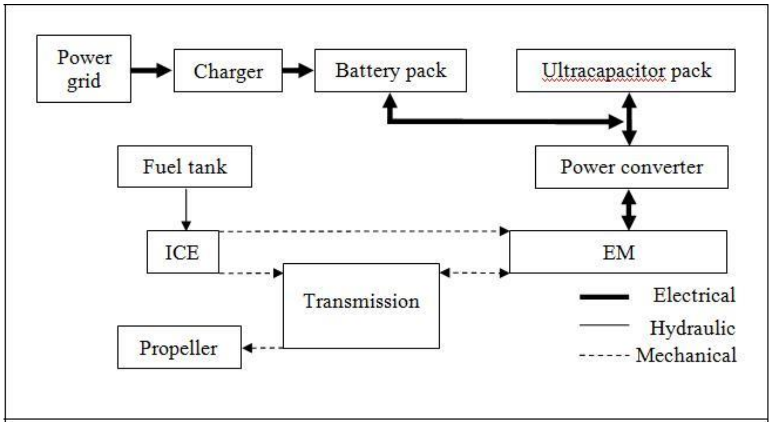


Figure 1 Schematic illustration of series-parallel PHERB powertrain

2.0 PHERB PARAMETERS, SPECIFICATIONS AND REQUIREMENTS

To meet the PHERB powertrain design specifications and requirements, component sizing and selection for the EM, ICE and ESS was conducted. Based on the boat power requirements for steady state velocity, the main components of PHERB powertrain were sized according to the boat parameters, specifications and performance requirements. After the sizing process, the components were selected based on the specifications and requirements of each component. Based on the PHERB parameters, target specifications and performance requirements in Table 1, the power requirements of the boat can be determined using boat dynamic equations [1 - 5]. The power required, P_{req} for a boat as shown in Figure 2 is calculated using this equation where P_E is an effective power and η_T is the total propulsive efficiencies.

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

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

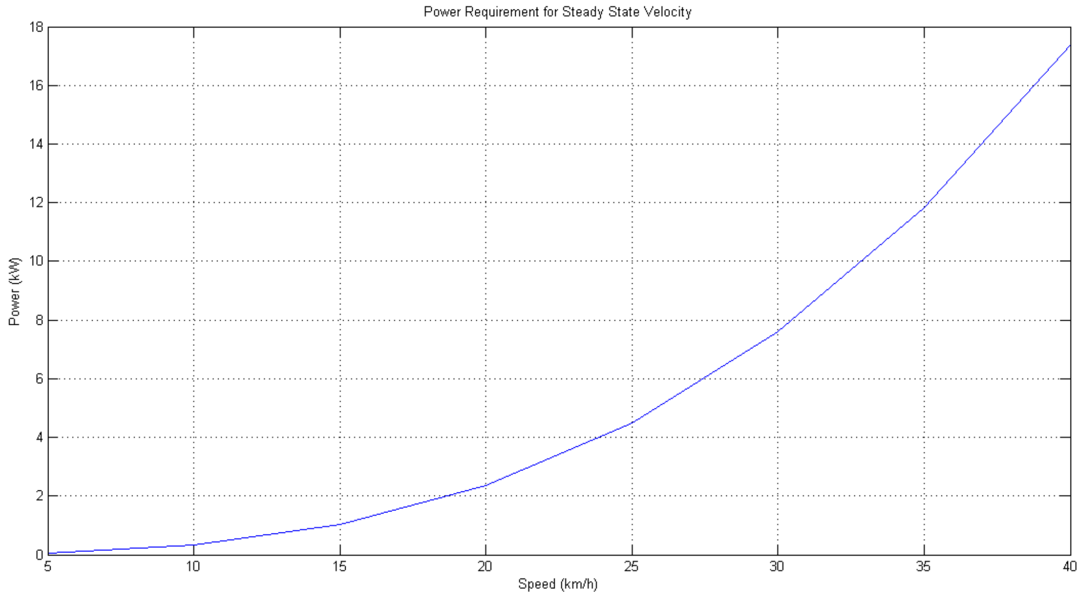


Figure 2 Boat power requirements for steady state velocity

3.0 MAIN COMPONENTS SIZING

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

3.1 Electric Machine (EM)

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

3.2 Internal Combustion Engine (ICE)

The ICE requirements are determined by the average power requirements in the series PHERB 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

3.3 Energy Storage System (ESS)

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

4.0 SELECTED COMPONENTS PARAMETERS AND SPECIFICATIONS

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

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
Battery	Li, 5 kWh, 6 Ah

5.0 DATA ANALYSIS

Then, the analysis on the influence of different drive cycles on the individual components that make up the overall structure is carried on the PHERB powertrain using Kuala Terengganu (KT) river drive cycle as shown in Figure 3 cycles on the individual components that make up the overall structure is carried on the PHERB powertrain using Kuala Terengganu (KT) river drive cycle as shown in Figure 3. The KT drive cycle lasts for 2414 s covering a distance of 12.09 km with an average speed of 18.02 km/h and maximum speed of 22 km/h. Based on the PHERB power requirement as illustrated in Figure 4, the components sizing for KT river drive cycle are listed in Table 3.

Table 3 Components sizing for kt river drive cycle

EM	
P_{EM} (22 km/h)	3.1 kW
P_{EM}, continuous = P_{EM} (20 km/h)	2.2 kW
ICE	
P_{ICE}, continuous = P_{EM} (15 km/h)	1.1 kW
P_{ICE}, continuous	1.5 kW
ESS	
P_{EM} (10 km/h)	0.3 kW
E_{ESS}, min	0.5 kWh
P_{ESS}, max	1.7 kW
E_{ESS}	0.6 kWh

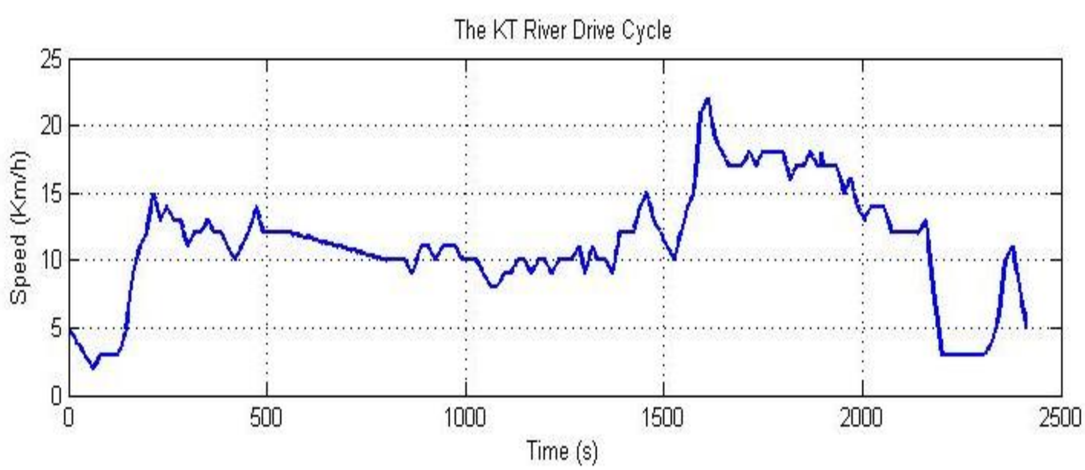


Figure 3 The KT river drive cycle

6.0 CONCLUSIONS

The most critical task to design an optimal power management boat in terms of all-electric drive performance and energy efficiency is sizing and selecting the PHERB powertrain main components. Based on the boat parameters, specifications and performance requirements, the individual components that make up the overall structure of the PHERB powertrain are chosen using the different drive cycles.

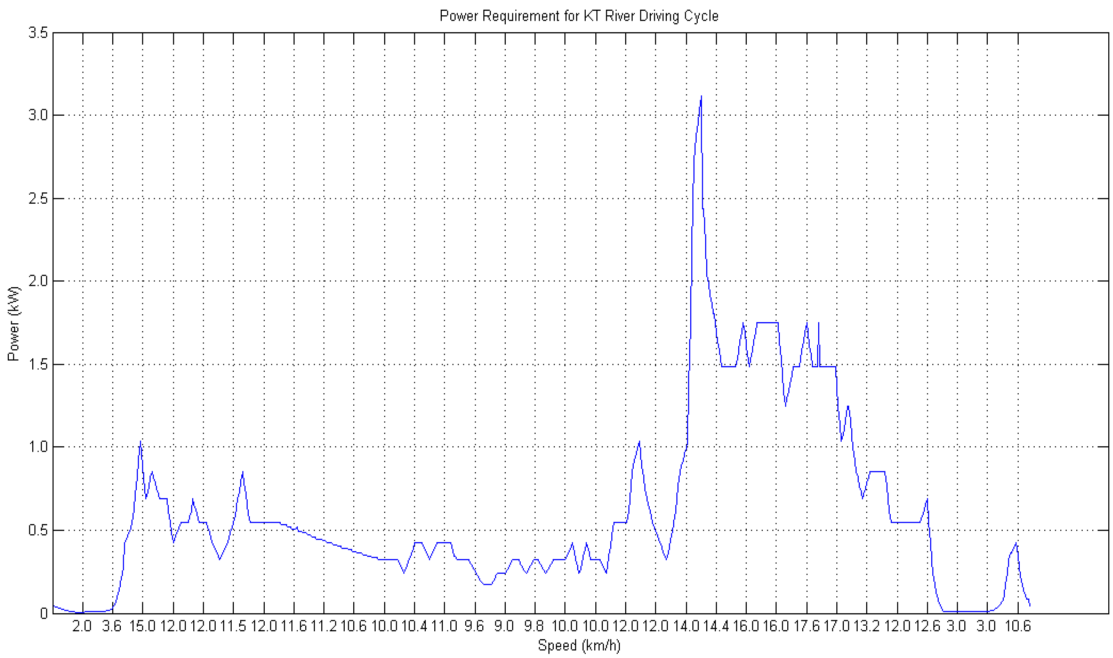


Figure 4 Boat power requirements for KT river driving cycle

Acknowledgments

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