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Component sizing in PHERB powertrain using PK driving cycle

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Abstract: The fuel consumption and emissions nowadays are increasing. Marine transportation is not excluded in this issue. So that, a main components sizing for series-parallel plug-in hybrid electric recreational boat (PHERB) powertrain is introduced in this paper. 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 Pulau Kapas driving cycle. The results obtained from this analysis are within reasonable range and satisfactory.

Key words: Component sizing; PHERB; Powertrain; Fuel consumption; Emissions

1. Introduction

In recent years, when the future of automotive powertrains is discussed, the emphasis on reducing the carbon dioxide emissions is significant (Emilia et al., 2012). Plug-in hybrid electric vehicles are a promising alternative to gas-only vehicles and offer the potential to greatly reduce fuel use in transportation (Dominik et al., 2008). The expected potential energy consumption of PHERB powertrain is highly linked to the size of components. Therefore, in order to reduce the fuel consumption and emissions, the component sizing of powertrains are important. In this paper, components sizing for plug-in hybrid electric recreational boat (PHERB) powertrain using steady state velocity and Pulau Kapas (PK) driving cycle is presented. Fig. 1 shows a schematic illustration of the proposed series-parallel PHERB powertrain. Kapas Island or Pulau Kapas is an island located about 6 kilometers east of Marang, Malaysia, with a smaller island, Pulau Gemia, located north of it. It measures roughly 1.5 by 2.5 km. The selected PK route is shown in Fig. 2.

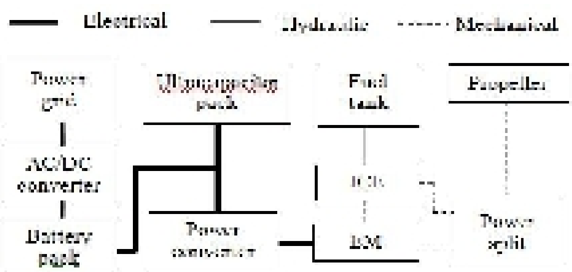

Fig. 1: A schematic illustration of the proposed series-parallel PHERB powertrain

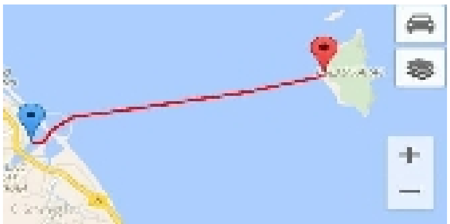

Fig 2: The PK route map

2. PHERB parameter, specification and requirements

To identify the main components of PHERB powertrain, design specifications, requirements, sizing and selection for electric machine (EM), internal combustion engine (ICE) and energy storage system (ESS) are carried out. The EM, ICE and ESS are sized according to boat parameter, specifications and performance requirements listed in Table I, based on the boat power requirement for steady state velocity using dynamic equation boat (Miami et al., 2013; Miami et al., 2010).

Table 1: PHERB Parameters, Specifications and Performance Requirements

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

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The power required, $Preq$ for a boat as shown in Fig. 3 is calculated using equation (1) where PE is an effective power and ηT is the total propulsive efficiencies:

(1) $Preq = PE \times \eta T$

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

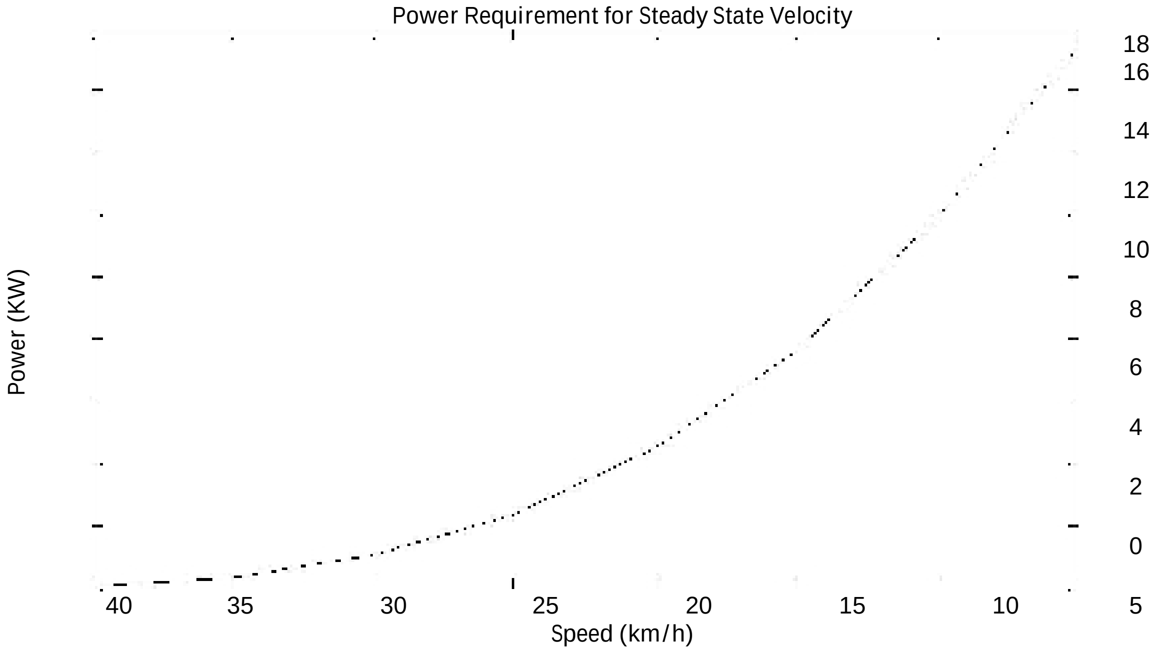

Fig. 3: Boat power requirements for steady state velocity

3. PHERB 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)

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:

PEM (40 km/h) = 17.4 kW

The power requirement of the electric propulsion motor is determined by the maximum speed. The

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:

PEM, continuous = PEM (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:

PICE, continuous = PEM (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:

PICE, 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:

PEM (10 km/h) = 0.4 kW

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

EESS, 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.

PESS, max = 1.5 x PEM, continuous - PICE, 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.

EESS = PESS, max / 3 x h = 2 kWh

3.4. Selected main 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

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

4. Results and discussions

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 PK driving cycle as shown in Fig. 4. The PK driving cycle lasts for 655 s covering a distance of 1.89 km with an average speed of 28.77 km/h and maximum speed of 49.26 km/h. Based on the PHERB power requirement as illustrated in Fig. 5, the components sizing for PK driving cycle are listed in Table 3.

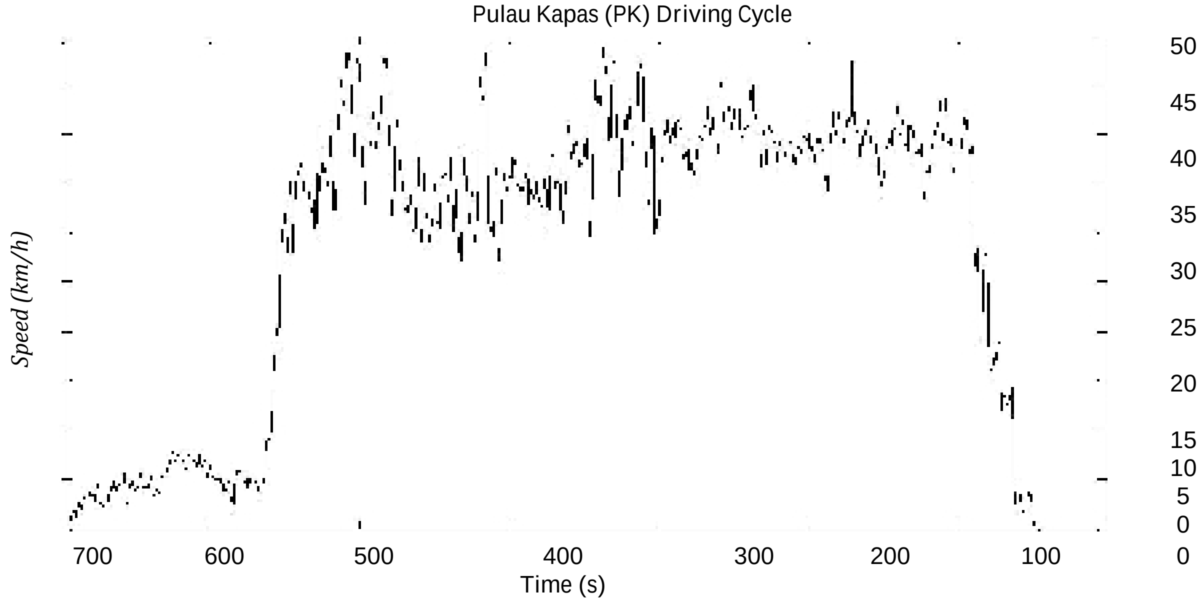

Fig. 4: The PK River driving cycle

Table 3: Components sizing for PK river driving cycle

	EM
31.66kW	PEM (49.3 km/h)
17.42kW	PEM, continuous = PEM (40 km/h)
	ICE
11.94kW	PICE, continuous = PEM (35 km/h)
14.00kW	PICE, continuous
	ESS
2.45kW	PEM (20 km/h)
4.08kWh	EESS, min
5.13kW	PESS, max
1.71 kWh	EESS

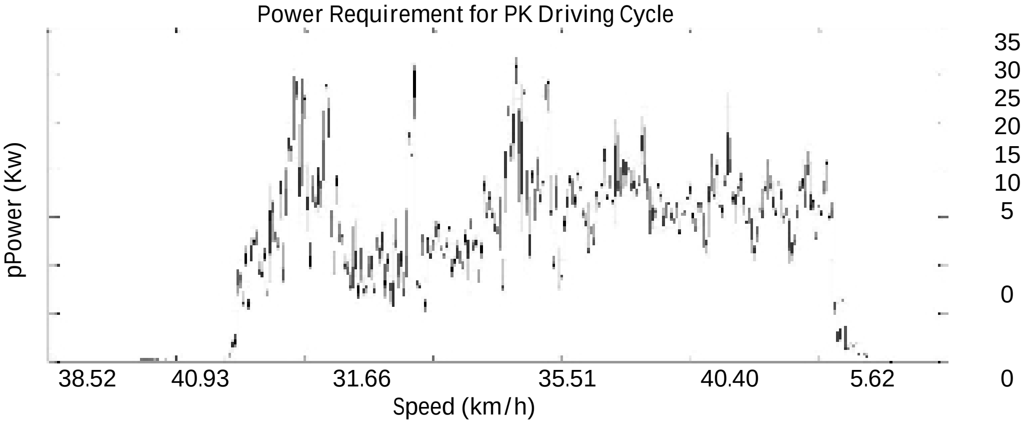

Fig. 5: PHERB power requirements for PK driving cycle.

5. 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. The results of EM, ICE and ESS sizing for PK river driving cycle based on the boat parameters, specifications and performance requirements, are within reasonable and expected range. It can be concluded that the individual main components that make up the overall structure of the PHERB powertrain using PK river driving cycle are correct.

Acknowledgement

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