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# A Comparative Study on Components Sizing for Conventional Boat and Pherb Powertrains using Water Driving Cycle

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**ABSTRACT**

In this paper, the water driving cycle had been chosen to determine and compare the component sizing of conventional boat and Plug-in Hybrid Electric Recreational Boat (PHERB) powertrains. PHERB is an improvement on conventional boat to reduce the fuel consumption and emissions. The locations of water driving cycle in this research are at Pulau Kapas and Tasik Kenyir, Terengganu. Boat energy and power requirement was calculated according boat parameters, specifications and performance requirements to study the differences component sizing of conventional boat and PHERB powertrains. Power flow analyses are used to decide the size and capacity of main components for achieving the design specifications and requirements of conventional boat and PHERB powertrains. The results for PHERB powertrain requirement using steady state velocity are 20 kW at 3000 rpm for Internal Combustion Engine (ICE), 30 kW for Electric Machine (EM) and 5 kWh for Energy System Storage (ESS). The acquired results show that the PHERB gained the most existing powertrains and has extraordinary potential in applications to marine transportation in reducing fuel consumption and emission.



## 1. Introduction

Terengganu is a coastal state strategically located on the eastern seaboard of Peninsular Malaysia and is surrounded by many islands. As such, water transportation becomes a major means of transportation to connect the main island to other islands in Terengganu to carry passenger and goods among others. Normally, the marine transportation is considered a conventional boat that is powered by a diesel engine [1-3]. The use of diesel engine can produce emissions that can affect the environment.

The operation of marine diesel engine contributes to the greenhouse outcome and to the development of acid rain effect of the over-fertilisation of lakes and soil [4-5]. The radiated rate of carbon monoxide (CO) is practically immaterial in lean blends (Fuel to air proportion (Fo1)). Other emission gases are the oxides of nitrogen (NOx), particulate matter or sediment (PM). Optional

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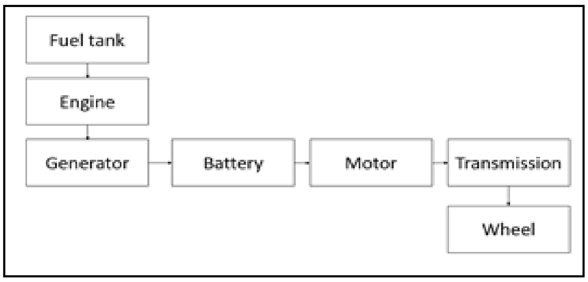
emissions are sulfur oxides (SOx) and unburned hydrocarbons (HC), as displayed in Table 1 [4-6]. The expanding use of fuel in diesel motor can cause in the diminishing of sources.

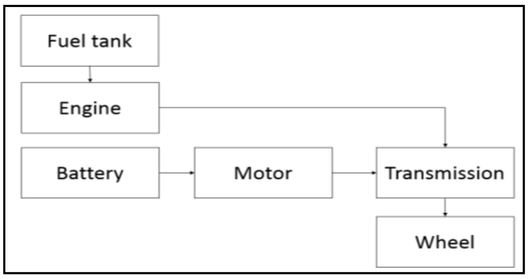
**Table 1**
Emission factors for low speed engines [4-6]

| Pollutant type | Static average Power based factor [g/kWh] | Fuel based factor [tonnes/day] |
|---|---|---|
| $PM_{10}$ | 1.5 | – |
| $PM_{2.5}$ | 1.2 | – |
| DPM | 1.5 | – |
| $NO_x$ | 17 | 0.087 |
| $SO_x$ | 10.5 | 0.02*%Sulphur |
| CO | 1.4 | 0.0074 |
| HC | 0.6 | – |
| $CO_2$ | 620 | 3.17 |
| $N_2O$ | 0.031 | – |
| $CH_4$ | 0.006 | 0.0003 |

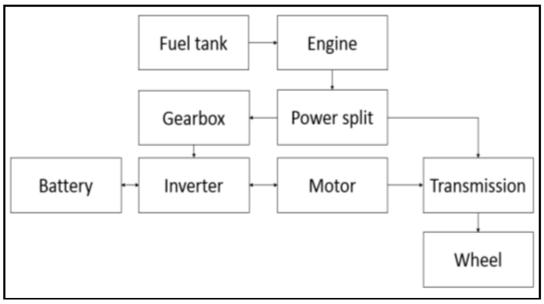
In marine diesel engine, the efficiencies of marine diesel engines have increased in recent decades [8-9] and efforts are being continued to reduce specific fuel consumption and associated pollution [10]. In some cases, efforts to reduce NOx and SOx pollutants will result in an increased specific fuel consumption [11]. Hybrid electric vehicle (HEV) will be a new type of clean and energy efficient powertrains, where the need for it is considered urgent in order to boost the fuel economy, increase the all electric range (AER), and at the same time, mitigate the harmful emissions [12-13]. In general, a HEV is used as internal combustion engine (ICE) to drive the boat and electric machine (EM) as a generator to charge the energy system storage [14-16]. Nowadays, there are three types of drivetrain configuration, which are the series hybrid, parallel hybrid and combined series-parallel hybrid [17-18], as shown in Figure 1.




(a)




(b)




(c)

**Fig. 1.** The HEV drivetrain; (a) series hybrid, (b) parallel hybrid and (c)combined series-parallel hybrid

In this paper, the series-parallel (PHERB) innovation on conventional boat is introduced to minimize the fuel consumption and emission level [4-5]. In this study, the components sizing of PHERB was determined using power flow method. Besides that, components sizing between conventional boat and PHERB powertrains were compared using different driving cycles, which are Kapas Island driving cycle and Kenyir Lake driving cycle.

## 2. Methodology

Design specifications, requirements and configurations are carried out in order to identify the main components of conventional boat and PHERB powertrains.

### *2.1 Configuration of Conventional Boat and PHERB*

In conventional boat powertrain, the main power to drive the boat is the engine, through the use of fuel. Mostly, diesel engines are used in the propulsion system. In this system, the gearbox is used to controlthe speed of engine in a certain ratio. Thus, the propeller speed can also be controlled. A schematic illustration of conventional boat powertrain is shown in Figure 2.

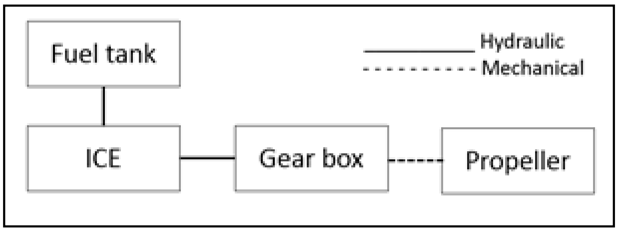



**Fig. 2.** Schematic illustration of conventional boat powertrain

In the PHERB powertrain as shown in Figure 3, the main control source to drive the boat is the electric machine (EM). The essential vitality of the EM is the battery pack to supply consistent power to the boat and the secondry vitality source is the ultracapacitor pack which is utilized to retain the power pulses amid regenerative braking and control for peak acceleration. The ICE is set as a reinforcement control source. It works under specific conditions and will not be turned on at all times in order to reduce the fuel consumption and emission. The size of the ICE can be at ist minimum since its power is required only when the battery condition of state of charge (SOC) level is low and to give required additional torque to help the EM to work the boat amid high torque drive condition.

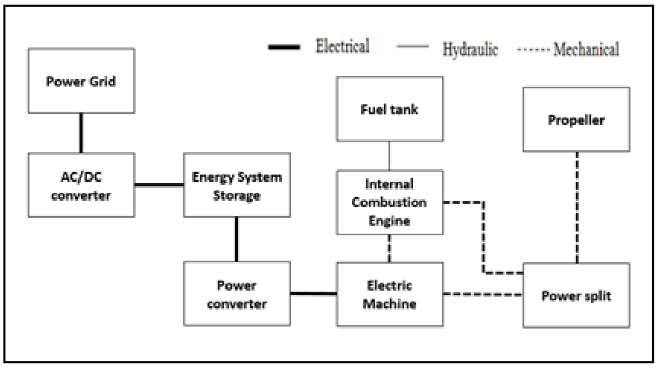



**Fig. 3.** Schematic illustration of PHERB powertrain [19]

### 2.2 Parameters and Specifications of Conventional Boat and PHERB

To find the conventional boat and 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 conventional boat and PHERB powertrain were sized according to the boat parameters, specifications and performance requirements. After the sizing process, the components were selected based on specifications and requirements of each component.

## 3. Results and Discussion

Power requirement using steady state velocity and different driving cycle is explained in this section. Power requirement are used to determine component sizing of conventional boat and PHERB using Pulau Kapas and Tasik Kenyir driving cycles.

### 3.1 Power Requirement using Steady State Velocity

The conventional boat and PHERB power required for steady state velocity as shown in Figure 4 is calculated using Eq. (1), where PE is an effective power and ηT is the total propulsive efficiencies [20].

$$Preq = PE \times \eta T \tag{1}$$

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

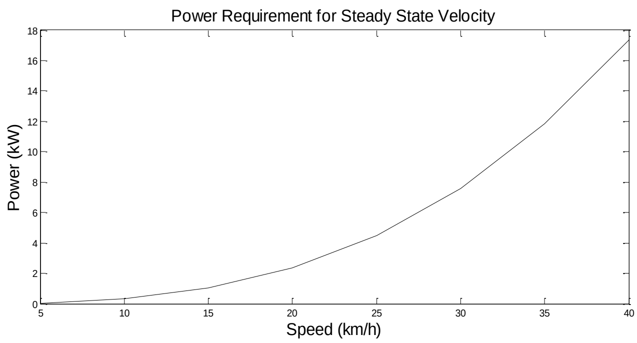



**Fig. 4.** Power Requirement for steady state velocity

### 3.2 Conventional Boat Powertrain Sizing using Steady State Velocity

In conventional boat, the ICE powertrain undergoes sizing. The ICE is determined by power requirement in the PHERB series concept. At 40 km/h in cruising mode, the maximum velocity is assumed to achieve the power in the worst case scenario. The continuous ICE output power are found to be 17.4 kW.

### 3.3 PHERB Powertrain Sizing using Steady State Velocity

ICE, EM and energy system storage (ESS) were sized in PHERB powertrain. In ICE, the requirements in PHERB series are determined. In this scenario, the maximum velocity assumed at 30 km/h in cruising mode are defined as the power in the worst case. The continuous ICE output power in the sizing powertrain in PHERB is 7.6 kW. At an estimated efficiency of 85%, the mechanical input power has to be 20 kW, which is the minimum continuous ICE power requirement. Hence, the electric output power is 18 kW, while, the minimum requirement of continuous ICE power is 10 kW and the electric power is 8 kW.

In EM sizing, the power needed for electric motor propulsion is defined by the maximum speed. Maximum speed is assumed as 40 km/h. Maximum mass was considered in all calculations. Therefore, 17.4 kW of propulsion power is needed to achieve 40 km/h.

For ESS, the available energy and maximum power are the two main ESS conditions. The available energy should be adequate in pure electric driving mode, which is 10 km/h. Thus, the power needed to propel the boat is 0.4 kW.

The overall drivetrain efficiency is assumed to be 60%, where the required battery storage capacity is at least 0.7 kWh for pure electric range. Meanwhile, to boost the power propulsion, the battery power should be sufficient. The amount needed is 6 kW. In full performance, a maximum discharge is assumed as well. Consequently, 2 kWh is determined as the battery storage capacity.

### 3.4 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.

**Table 2**
Main Components of the PHERB and conventional Boat Powertrain for Steady State Velocity

| Type of Boat | PHERB | Conventional Boat |
|---|---|---|
| **Component** | **Specifications** | |
| ICE | 20 kW @ 3000 rpm | 50 kW @ 4000 rpm |
| EM | 30kW AC<br>Induction motor | - |
| ESS | Li, 5kWh, 6 Ah | - |

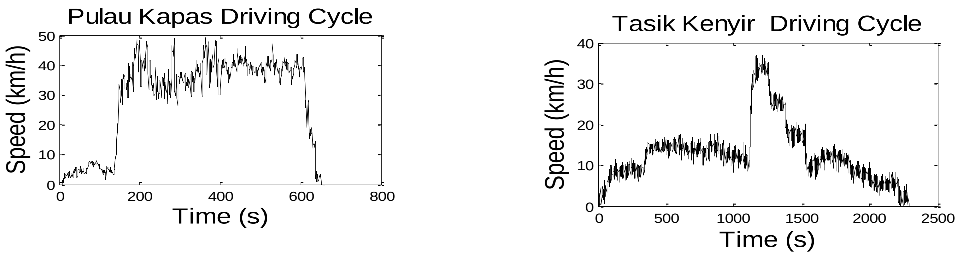
### 3.5 Power Requirement using Different River Driving Cycle

The analysis on the influence of actual developed driving cycle on the individual components that make up the overall structure is carried out on the conventional and PHERB powertrains using Pulau Kapas and Tasik Kenyir route map and driving cycles, are shown in Figure 5 and 6.

The Pulau Kapas drive cycle lasts for 655 s, covering a distance of 1.89 km with an average speed of 28.77 km/h and a maximum speed of 49.26 km/h. For Tasik Kenyir, the drive cycle lasts for 2293 s, covering a distance of 2.95 km with an average speed of 12.85 km/h and a maximum speed of 36.91 km/h. From the drivng cycle of each location, the power requirement was calculated using equation (1).


(a) Pulau Kapas (b) Tasik Kenyir

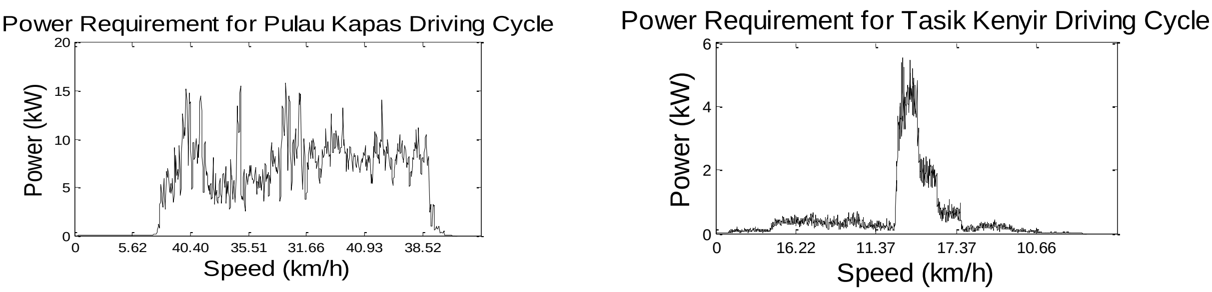
**Fig. 5.** The route map




(a) (b)

**Fig. 6.** The driving cycle used; (a) Pulau Kapas, (b) Tasik Kenyir

The graph of power requirement for Pulau Kapas and Tasik Kenyir are shown in Figure 7. Based on the PHERB power requirement as illustrated in Figure 5, the components sizing for Pulau Kapas and Tasik Kenyir drive cycles are listed in Table 3. The need for power PHERB of ICE, EM, and ESS was lesser than that of conventional boat. This shows that PHERB uses minimum power to drive the boat than a conventional boat would. Besides that, the power of PHERB component sizing in Table 3 is in the expected range for each component stated in Table 2.




(a) (b)

**Fig. 7.** Power requirements for different driving cycle; (a) Pulau Kapas; (b) Tasik Kenyir

## 4. Conclusion

Power and capacity for EM, ICE and ESS results are within reasonable and expected range of the component sizing for comparison using steady state and different driving cycle and it can be concluded that the individual components that make up the overall structure of the PHERB powertrain size is maximum compared to conventional boat.

**Table 3**
Components Sizing for different driving cycle

| Driving cycle | Steady state velocity | | Pulau Kapas driving cycle | | Tasik Kenyir driving cycle | |
|---|---|---|---|---|---|---|
| **Type of Boat** | **PHERB (kW)** | **CB (kW)** | **PHERB (kW)** | **CB (kW)** | **PHERB (kW)** | **CB (kW)** |
| | | | **EM** | | | |
| $P_{EM}$ max | 17.4 | - | 20.0 | - | 13.8 | - |
| $P_{EM}$, continuous max | 11.8 | - | 17.4 | - | 7.6 | - |
| | | | **ICE** | | | |
| $P_{ICE}$, continuous = $P_{EM}$ max | 7.6 | 17.4 | 11.9 | 22.4 | 4.5 | 16.5 |
| $P_{ICE}$, continuous max | 10.0 | 20.0 | 14.0 | 28.5 | 5.0 | 21.9 |
| | | | **ESS** | | | |
| $P_{EM}$ max | 0.4 kW | - | 2.5 kW | - | 2.4 kW | - |
| $E_{ESS}$, min | 0.7 kWh | - | 4.1 kWh | - | 4.1 kWh | - |
| $P_{ESS}$, max | 6.0 kW | - | 5.1 kW | - | 6.4 kW | - |
| $E_{ESS}$ | 2.0 kWh | - | 1.7 kWh | - | 2.1 kWh | - |

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## References
[1] Ferry, M. "Comparative Study of Hybrid Catamaran Versus Diesel Monohull Boat as Ferry for Short Distance Routes." *The Indonesian Journal of Naval Architecture* 1, no. 1 (2013).
[2] Karimpour, Reza, and Maryam Karimpour. "Development of Hybrid Propulsion System for Energy Management and Emission Reduction in Maritime Transport System." *Marine Science* 6 (2016): 482-497.
[3] Kjartansson, Sveinbjörn. "A Feasibility Study on LPG as Marine Fuel." (2012).
[4] IMO, 2009. Second IMO Green House Emission Study. International Maritime Organisation. Report. MEPC 59.
[5] Dedes, Eleftherios K., Dominic A. Hudson, and Stephen R. Turnock. "Assessing the potential of hybrid energy technology to reduce exhaust emissions from global shipping." *Energy policy* 40 (2012): 204-218.
[6] Eyring, Veronika, Ivar SA Isaksen, Terje Berntsen, William J. Collins, James J. Corbett, Oyvind Endresen, Roy G. Grainger, Jana Moldanova, Hans Schlager, and David S. Stevenson. "Transport impacts on atmosphere and climate: Shipping." *Atmospheric Environment* 44, no. 37 (2010): 4735-4771.
[7] EMEP/CORINAIR, 2002. EMEP Co-operative Programme for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe, The Core Inventory of Air Emissions in Europe (CORINAIR). Atmospheric Emission Inventory Guidebook.
[8] Kyrtatos, N. "Marine Diesel Engines and technologies for emission reduction." In *EnergyReS 2009 Scientific Forum. EnergyReS, Athens*. 2009.
[9] Anantharaman, Mohan, Vikram Garaniya, Faisal Khan, and Barrie Lewarn. "Marine Engines and their Impact on the Economy, Technical Efficiency and Environment." *Marine Engineering* 50, no. 3 (2015): 360-367.
[10] MAN Diesel. 2009. Emission Control MAN B&W Two-stroke Diesel Engines. MAN B&W Deisel A/S, Copenhagen.

[11] Chryssakis, C., A. Frangopoulos, and L. Kaiktsis. "Computational study of incylinder NOx reduction in a large marine diesel engine using water injection strategies." *Society of Automotive Engineers* (2010).
[12] Abdul Rahman, S., P. D. Walker, N. Zhang, J. Zhu, and H. Du. "A Comparative study of vehicle drive performance and energy efficiency." In *International Conference on Sustainable Automotive Technologies*. Springer, 2012.
[13] Ehrhardt-Martinez, Karen, and A. John. "People-centered initiatives for increasing energy savings." American Council for an Energy-Efficient Economy., 2010.
[14] Rashid, Muhammad Ikram Mohd, Hamdan Daniyal, and Danial Mohamed. "Comparison performance of split plug-in hybrid electric vehicle and hybrid electric vehicle using ADVISOR." In *MATEC Web of Conferences*, vol. 90, p. 01019. EDP Sciences, 2017.
[15] Liu, Wei. *Introduction to hybrid vehicle system modeling and control*. John Wiley & Sons, 2013.
[16] Zulkifli, Saiful A., Nordin Saad, Syaifuddin Mohd, and A. Rashid A. Aziz. "Split-parallel in-wheel-motor retrofit hybrid electric vehicle." In *2012 IEEE International Power Engineering and Optimization Conference Melaka, Malaysia*, pp. 11-16. IEEE, 2012.
[17] Husain, Iqbal. *Electric and hybrid vehicles: design fundamentals*. CRC press, 2010.
[18] Sabri, M. F. M., K. A. Danapalasingam, and M. F. Rahmat. "A review on hybrid electric vehicles architecture and energy management strategies." *Renewable and Sustainable Energy Reviews* 53 (2016): 1433-1442.
[19] Norbakyah, J. S., W. H. Atiq, and A. R. Salisa. "Powertrain main components sizing of PHERB using KL River driving cycle." *ARPN Journal of Engineering and Applied Sciences* 10, no. 18 (2015): 8507-8510.
[20] Norbakyah, J. S., W. H. Atiq, and A. R. Salisa. "Components sizing for PHERB powertrain using ST river driving cycle." In *2015 International Conference on Computer, Communications, and Control Technology (I4CT)*, pp. 432-436. IEEE, 2015.