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Research paper

A Study on Electrical Consumption, All Electric Range, Fuel Economy And Emissions of Plug-in Hybrid Electric Recreational Boat (PHERB) Powertrain

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Abstract

Plug-in hybrid vehicle (PHEV) have capability to reduce fuel consumption and emission attainment the attention around the world. Marine transportation such as boat also need innovation from conventional to PHEV because marine transportation also contributor to pollution. Plug-in hybrid recreational boat (PHERB) is an innovation for recreational boat in marine transportation industry. This paper is focused on the all-electric range (AER), electrical consumption, fuel economy and emissions at different initial and target state of charge (SOC) of the battery on the PHERB powertrain using different water driving cycle. In this research, the model of PHERB is derived and implemented numerically in the MATLAB/SIMULINK environment with a special energy management strategy (EMS) was built. The analysis of all-electric range (AER) and electrical consumption in different initial and target SOC were studied. Hence, the fuel economy and emission were analyzed and compared.

Keywords: *PHERB; electrical consumption; fuel economy; emission; water driving cycle*

1. Introduction

In Malaysia, there are three type of vehicle used such as land vehicle, water vehicle and air vehicle. Vehicles are used to move the people, animals and goods from one location to another location. But, the impacts of vehicles use make our environment be polluted. To overcome this problem, the vehicles have a revolution that is starting from conventional, electric, hybrid electric and plug-in hybrid electric vehicle. However, this revolution only focuses or synonym with land vehicles such as cars and so on. Marine transportation also contributed to the environmental pollution especially water pollution. Boats are designed for recreational, 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 [1]. So, this marine transportation need to change from the conventional boat (CB) to be the environmental friendly boat. Fig 1 displayed the powertrain of CB powertrain. CB powertrain contain internal combustion engine (ICE) only.

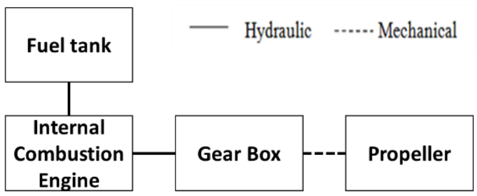


Fig. 1: Block diagram of the CB powertrain

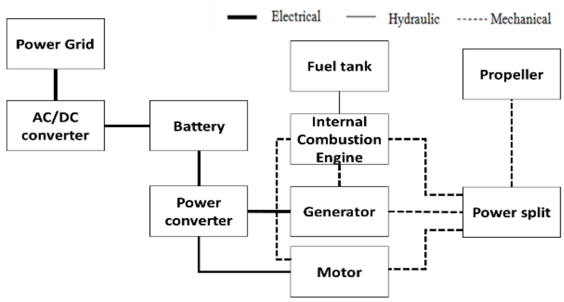


Fig. 2: Block diagram of the PHEB powertrain

In reducing harmful emission and fuel consumption, [2] was presented plug in hybrid electric boat (PHEB). The PHEB model contains two separate electric machine (EM), which are used as the motor and generator, respectively, and an energy system storage (ESS) with no ultracapacitor (UC) bank.In 2013, Minami was upgraded their PHEB was known as PHEB-2 [3]. The PHEB powertrain of PHEB-1 and PHEB-2 was shown in Fig 2. In this studied, plug-in hybrid electric recreational boat (PHERB) was introduced [4]. The proposed PHERB has only one EM which functions as either a motor or generator at a time and in the ESS there is UC bank for fast charging and discharging during the regenerative braking and fast acceleration. The full size of ICE in is required because when the state of charge (SOC) of the ESS is low, the ICE were move the boat alone. The ICE in PHERB can move the boat while charging the ESS until the ESS SOC reaches a high level and the EM were takeover to move the boat. A special energy management strategy (EMS) for the PHERB is needed to save the weight, space and cost plus improve all-electric range

(AER), the electrical consumption, fuel economy and emissions. So that, this paper are focusing on AER, the electrical consumption, fuel economy and emission of PHERB using different water driving cycle in different initial of SOC.

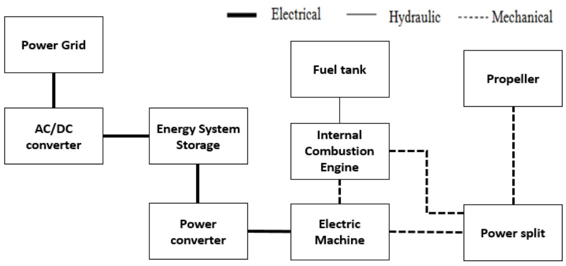


Fig. 3: Block diagram of the proposed PHERB powertrain

2. PHERB Development

The boat type selected is a recreational boat. Table 1 lists the parameters of PHERB parameters, specifications and performance requirements. In simulation, the length of boat used are 12.4 m and density of water are 1000 kgm-3. The development of boat model begins with the calculations of boat energy and power requirements for typical driving conditions based on the parameters and target specifications of the boat based on PHERB specification, parameter and requirement. The size and capacity of each boat component are then determined through a power flow analysis accordingly to meet the requirements. Table 2 displayed the size and specifications used for [6].

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, L_{PP}	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

Table 2: PHERB component and specifications

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

Combining of all components obtain a mathematical model of the boat. The boat performance for a given EMS and driving cycle is simulated in the MATLAB/SIMULINK environment. Fig 4 illustrated the overall structure of the PHERB model in MATLAB/SIMULINK.

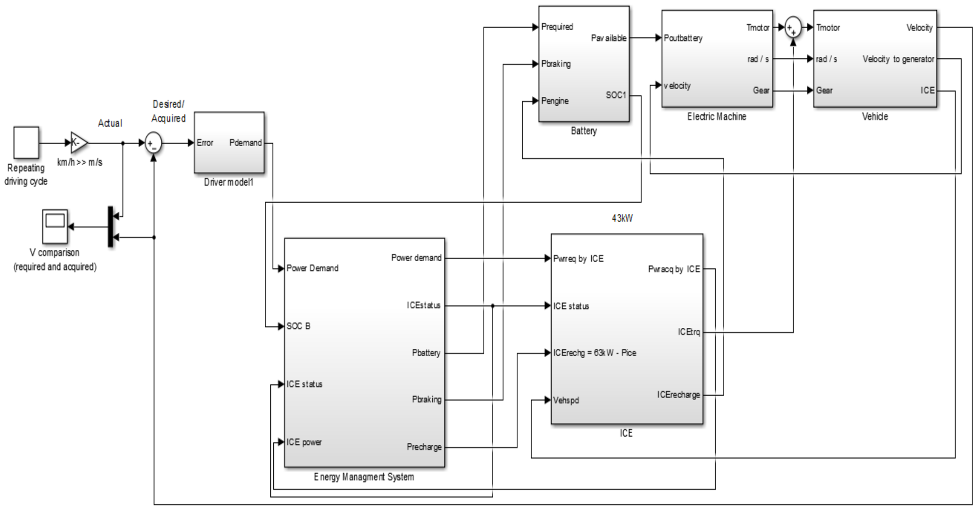


Fig. 4: Overall structure of the PHERB model in MATLAB/SIMULINK

3. Energy Management Strategy

EMS is responsible of choosing in which mode that the vehicle is functioning. Several operating modes of the proposed EMS to control the dispensation of power amongst the components, including the mechanical braking, regenerative braking, motor only, engine recharge, engine and motor assist, and engine only mode according to the boat power demand in acceleration and deceleration and the SOC level of ESS [7][8]. The illustrated of PHERB mode operation is shown in Figure 5.

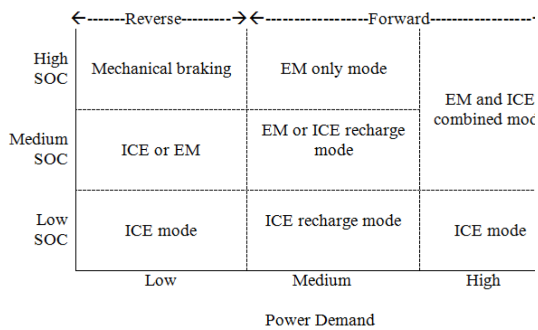
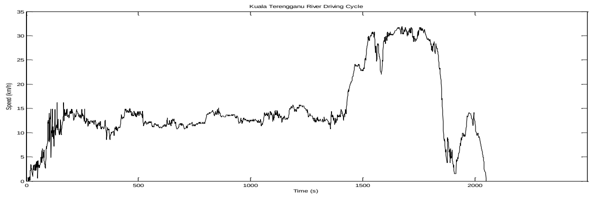


Fig 5: PHERB EMS modes of operation.

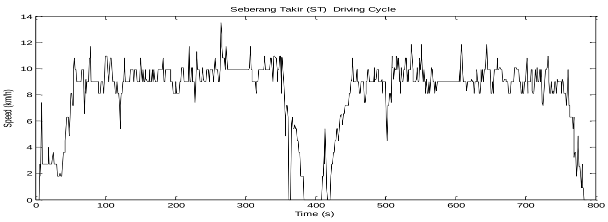
The mechanical braking mode is initiated if the SOC of both energy storage devices and/or the brake position is high. During the regenerative braking mode, the allocation of absorbed regenerative power depends on the percentage of brake position as well as on the SOC level of both storage units. EM only mode be activated when the SOC level is high. When the ESS SOC is low and the acceleration is low, the ICE were boost the boat while charging the energy storage devices. If the boat is cruising and the ESS has a moderate SOC, then the boat can be either ICE recharge or EM only mode. If the boat acceleration is high, then the ICE will not have an opportunity to charge the ESS, and the boat will use the ICE only mode to operate.

4. Driving Cycle

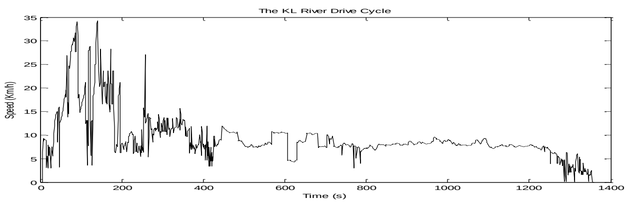
A driving cycle is a speed-time profile designed to represent a real-world driving pattern [9] [10]. Driving cycles are produced by different countries and organizations to assess the performance of vehicles in various ways, as for example fuel consumption and polluting emissions. Another use for driving cycles is in vehicle simulations. More specifically, they are used in propulsion system simulations to predict performance of internal combustion engines, transmissions, electric drive systems, batteries, fuel cell systems, and similar components. Besides that, electrical consumption, fuel economy and emission also can be known. In this research, river driving cycle were used such as Kuala Terengganu (KT) driving cycle, Seberang Takir (ST) driving cycle, and Kampung Laut (KL) driving cycle were exposed in Figure 6.



(a) KT driving cycle



(b) ST driving cycle



(c) KL driving cycle

Fig. 6: River driving cycles

5. Result and Discussion

This study is focused on the AER, electrical consumption, fuel economy and emissions at different initial SOCs of the battery on the PHERB powertrain using different river driving cycle. This analysis can be used in order to represent a typical daily trip on busy rivers. The distance covered by one driving cycle for KT driving cycle is 8.5 km with 2075 s, ST driving cycle is 1.7 km with 787 s and KL driving cycle is 3.5 km for 1360 s of duration.

5.1 Electrical Consumption and AER Analysis

For the analysis all-electric range (AER) and electrical consumption of PHERB, each test is started in EM only mode with a high SOC. The high SOC was applied at 90 % and the battery is allowed to discharge to a low SOC level. Before the start of the simulated boat test, the PHERB powertrain used several cycles of the different water drive cycle. The battery was charged to a high SOC level. The boat was run in the EM mode only until the ICE was on. This phenomena called as AER where the boat used 100 % EM mode only. For the different initial SOCs analysis, the boat was run with different initial SOCs from 90 % to 50 %, with an interval of 10 %. Tables 3 -5 shown electrical consumption and AER for different initial SOC for KT driving cycle, ST driving cycle and KL driving cycle.

Table 3: Electrical consumption and AER for different initial SOC used KT driving cycle

Initial SOC	Electrical consumption (Wh/km)	AER (km)
0.90	753	14.29
0.80	771	11.71
0.70	800	9.11
0.60	807	7.12
0.50	830	6.31

Table 4: Electrical consumption and AER for different initial SOC used ST driving cycle

Initial SOC	Electrical consumption (Wh/km)	AER (km)
0.90	1057	9.96
0.80	1057	8.47
0.70	1058	7.00
0.60	1069	5.56
0.50	1058	4.10

Table 5: Electrical consumption and AER for different initial SOC used KL driving cycle

Initial SOC	Electrical consumption (Wh/km)	AER (km)
0.90	2785	10.32
0.80	2632	7.80
0.70	2751	7.14
0.60	2568	4.76
0.50	2550	3.81

For the entire initial SOCs in the charge depleting mode, the boat was operated in the EM only mode from 90 % until 50 % was reached. The electrical consumption used KL driving cycle shown the higher depletion than other driving cycle. This is because the usage of battery in KL driving cycle are higher than KT driving cycle and ST driving cycle. Hence, the higher the initial SOC, the greater the distance can be covered by the boat in the EM mode only, and potentially increasing the fuel displacement.

5.2 Fuel Economy and Emission Analysis

The high and lower SOC for the battery is based on the effect on battery life of operation at different SOCs. The fuel economy and emissions were calculated for a different initial SOC set at 90 %, 80 %, 70 %, 60 % and 50 % after an electric-only discharge of the battery. Table 6 listed the impact of different initial SOCs of the battery on the boat fuel economy and emissions using different water driving cycle.

Table 6: Fuel economy and emission for different initial SOC used different water driving cycle

Driving Cycle	Initial SOC	Fuel economy (mpg)	Emission (g/s)		
			HC	CO	NOx
KT	0.90	184.6	0.558	0.285	0.000
	0.80	151.2	0.534	0.272	0.000
	0.70	117.7	0.554	0.283	0.000
	0.60	92.37	0.558	0.285	0.000
ST	0.50	81.43	0.575	0.293	0.000

	0.90	246.0	1.060	0.525	0.000
	0.80	209.2	1.056	0.530	0.000
	0.70	173.0	1.046	0.534	0.000
	0.60	137.3	1.163	0.593	0.000
	0.50	100.9	1.067	0.545	0.000
KL	0.90	214.0	0.906	0.463	0.000
	0.80	161.8	0.856	0.437	0.000
	0.70	148.0	0.895	0.457	0.000
	0.60	98.6	0.836	0.427	0.000
	0.50	78.9	0.836	0.427	0.000

According to the obtained results from this analysis, the initial SOC battery operation at 90 % until 50 % has an impact on boat fuel economy and emissions in different driving cycle. This is because of the different battery internal resistance during charging and discharging processes at different percentage, which represents a boat fuel displacement. From the results of fuel economy and emissions for different initial SOCs of different driving cycle, the higher the initial SOC were improve the boat energy consumption and emissions. So that, the higher initial SOC, electrical consumption and fuel economy can be increasing and reducing in emission.

6. Conclusion

As a conclusion, the chosen initial and target SOC of the ESS has significant effects on the boat AER, electrical consumption, fuel economy, and emissions. Different initial SOCs are analysed by the PHERB simulation model using water drive cycle and the best initial SOC of 90 % is obtained by optimizing the AER, electrical consumption, fuel economy and emissions of the boat.

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