

Optimization of the fuel economy and emissions for plug in hybrid electric recreational boat energy management strategy using genetic algorithm

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ABSTRACT

Today, the transportation sector has undergone a change from conventional vehicle to hybrid electric vehicle especially land-based with the aim to reduce fuel consumption and emissions. However, water transportation is also one of the contributors of excessive use of fuel and emissions. Therefore, water transport needs changes as it has been done on land transport, especially cars. In this paper, plug in hybrid electric recreational boat (PHERB) is introduced. PHERB is a special model because in PHERB powertrain configuration, it only needed one EM compared to existing configuration with energy management strategy (EMS). In this work, the optimal EMS for PHERB are presented via genetic algorithm (GA). To estimate the fuel economy and emissions, the model of PHERB is employed numerically in the MATLAB/SIMULINK environment with a special EMS using Kuala Terengganu (KT) river driving cycle. Simulation result of PHERB optimization using GA improve to 15 % for KT river driving cycles without violating the PHERB performance.

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1. INTRODUCTION

Nowadays, the fuel consumption and emission become big issues in transportation. This issue also effect the water transportation. In water transportation, the boat is used internal combustion engine to drive the boat. Plug-in hybrid electric vehicle give the great promising in reducing fuel economy and emission. Thus, water transportation needs the innovation to overcome these problems [1-4]. In this paper, Plug-in hybrid electric recreational boat (PHERB) is a new invention of recreational boat was presented [5]. The proposed PHERB is illustrated in Figure 1.

PHERB consists only one electric machine (EM) which functions as either a motor or generator at one time while in the energy system storage (ESS) there is ultracapacitor (UC) bank for fast charging and discharging during the regenerative braking and fast acceleration. The full size of ICE is required because when the state of charge (SOC) of the ESS is low, the ICE will move the boat alone until the ESS SOC reaches a high level and the EM will take over to move the boat. A special energy management strategy (EMS) for the PHERB is needed to improve the fuel economy and emissions. In this paper, the model of PHERB with a special EMS were developed mathematically numerical in MATLAB/SIMULINK is presented. The Kuala Terengganu driving cycle were used in PHERB model to analyse the PHERB performance. Genetic algorithm (GA) optimization were applied to parameter used in PHERB to improve the PHERB model in term of fuel consumption and emission. The minimum of fuel consumption and emission before and after optimize were compared.

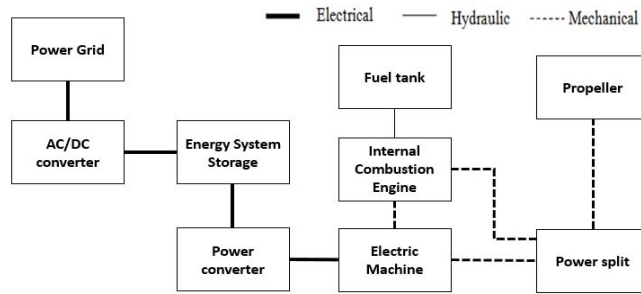


Figure 1. PHERB powertrain

2. PHERB DEVELOPMENT

Design specifications, requirements, sizing and selection for EM, ICE and energy storage system (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 (Table 1) based on the boat power requirement for steady state velocity using dynamic equation boat [6]. The boat type selected is a recreational boat. In simulation, the length of boat used is 12.4 m and density of water is 1000 kgm^{-3} . The enlargement of boat model starts with the estimations of boat energy and power needed for common driving situations based on the parameters and target specifications of the boat based on PHERB specification, parameter and requirement. Through a power flow analysis, the size and limit of each component are decided accordingly to get the necessities. Table 2 displayed the size and specifications used for PHERB. All parts in PHERB obtain a mathematical model is combined. The boat performance is simulated in the MATLAB/SIMULINK environment with a special EMS and different driving cycle. Overall structure of PHERB model is illustrated in Figure 2.

Table 1. Parameter, Specification and Configuration

Parameter and Specifications		
Type of boat	Conventional boat	PHERB
Configuration	Series	Series-Parallel
Length overall, L	12.4 m	12.4 m
Length at waterline, L_{WT}	11.0 m	11.0 m
Breadth, B	1.8 m	1.8 m
Draught, T	0.64 m	0.64 m
Length between perpendicular, L_{PP}	10.67 m	10.67 m
Density of water, ρ	1000 kgm^{-3}	1000 kgm^{-3}
Total propulsive efficiencies, η_T	0.9	0.9

Table 2. PHERB Component Specification

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

the cycle. In the ESS voltage graph, the voltage increases during regenerative braking, and decreases during high current discharge when the power demand from EM is at peak.

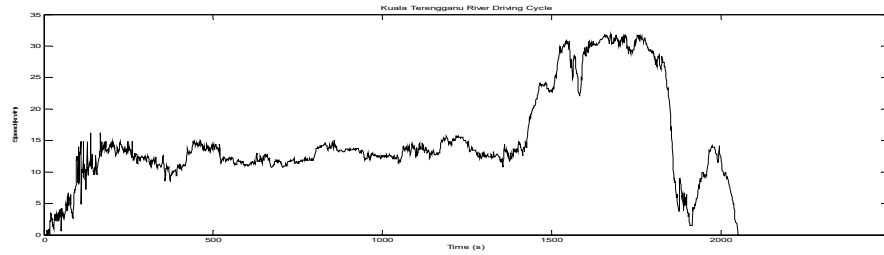


Figure 4. Kuala Terengganu driving cycle

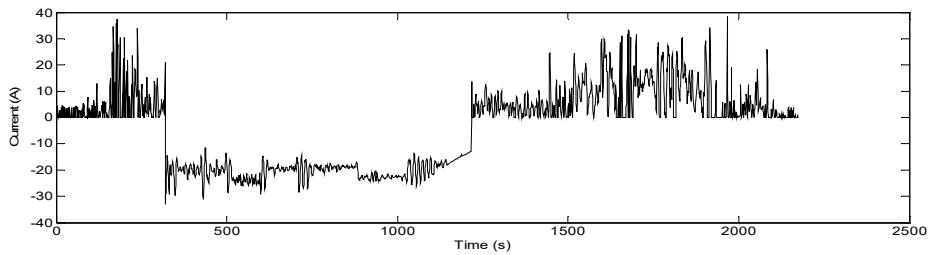


Figure 5. Current in ESS

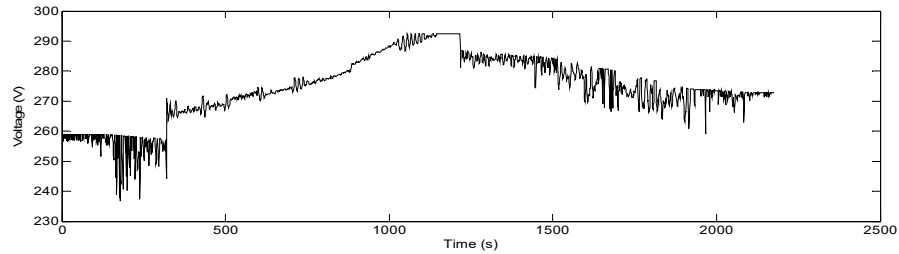


Figure 6. Voltage in ESS

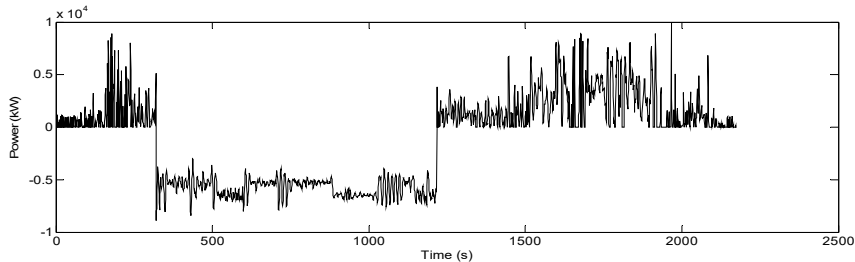


Figure 7. Power in ESS

Figure 8 – Figure 10 shows the simulated EM speed, torque and power. As shown in the figure, when the boat accelerates, the required EM torque increases quickly, and when it reaches the relatively stable velocity level, a much smaller torque is required to overcome the resistance and water drag to the boat.

The average power demand from the EM is 5 kW at the velocity level and the peak power demand is 13 kW during the acceleration boat.

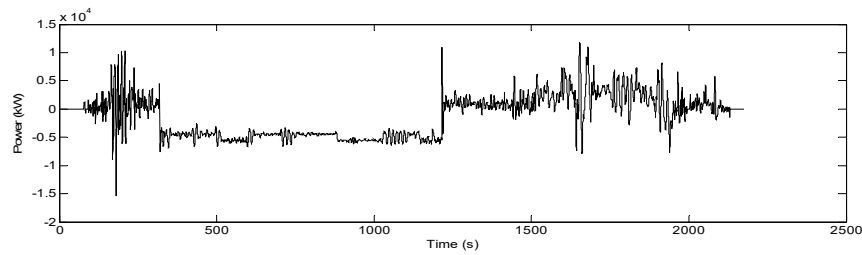


Figure 8. Power in EM

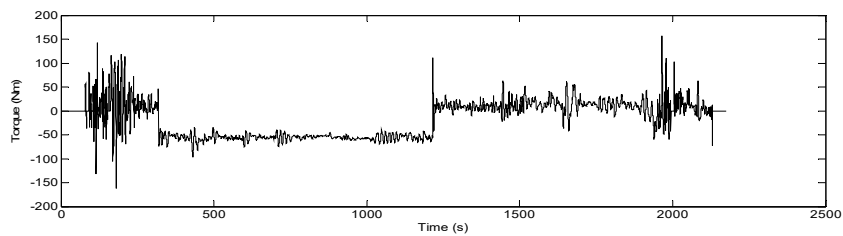


Figure 9. Torque in EM

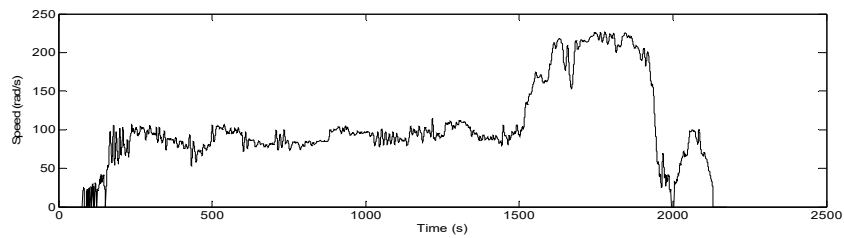


Figure 10. Speed in EM

Figure 11 – Figure 12 plots the simulated propeller speed and torque requirement for the KT drive cycle. The maximum propeller torque, 800 Nm, occurs when the boat is accelerating from standstill to the stable speed. The required torque then reduces since the KT drive cycle only consists of mild accelerations and decelerations.

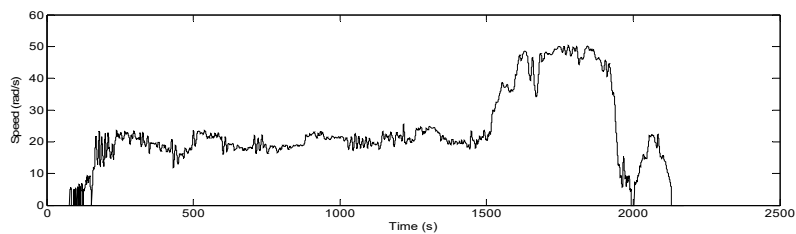


Figure 11. Propeller speed

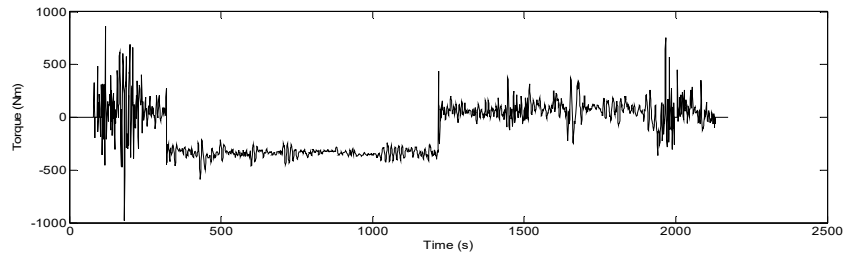


Figure 12. Propeller Torque

Figure 13 plots the simulated vehicle speed and the demanded speed for the KT drive cycle. As shown, the two curves match very well with a very small error of less than 0.05 m/s between the targeted and acquired speeds. So that, it is expected that the PHERB be able to provide drive performance as the conventional hybrid boat under the actual drive conditions.

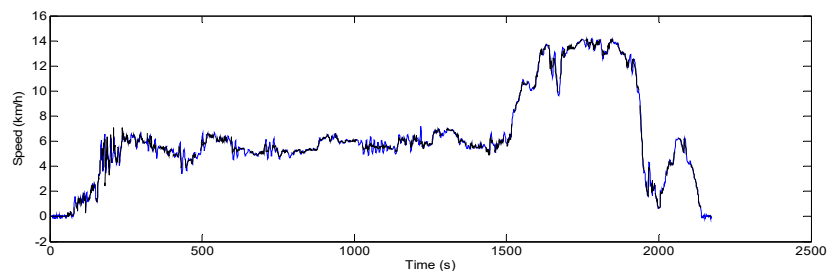


Figure 13. Actual and required speed

5. PHERB OPTIMIZATION

A process of knowing the minimum and maximum limits of an objective function while at the same time satisfying certain constraints on the design variables and also selecting the best combination in every iteration. In this study, the model in the loop approach are used to design optimization process. Firstly, the PHERB model simulation developed initial values of the design variable, and from this value, the numerical values of the objective function were appear. In this case, the value of fuel consumptions and emission decrease, which is imitated by four parameters including fuel usage, hydro-carbon (HC), carbon monoxides (CO) and nitrogen oxides (NO_x) level. The genetic algorithm (GA) is used in the model-based design optimization. It can be summarized briefly as illustrated in the flowchart of Figure 14. Table 3 shows a set of parameters used in this research [9]-[11]. The objective is to minimize the fuel consumption and emissions, such as HC, CO and NO_x, of the boat for the KT drive cycle.

The initial value of design variables given in Table 4 are simulated in PHERB model. Table 4 shows the six design variables used in this study. Each design variable is also restricted within a lower and an upper bound were stated in Table 5. The fuel consumption and emissions were observed for KT drive cycle. A comparison of the fuel economy and emissions before and after the optimization is given in Table 6. A significant improvement in the fuel used and emissions is achieved by optimization.

Table 3. Parameter used in GA

Parameters	Value
Population size	00
Crossover probability	70%
Mutation probability	1.75%
Maximum generation counted	200

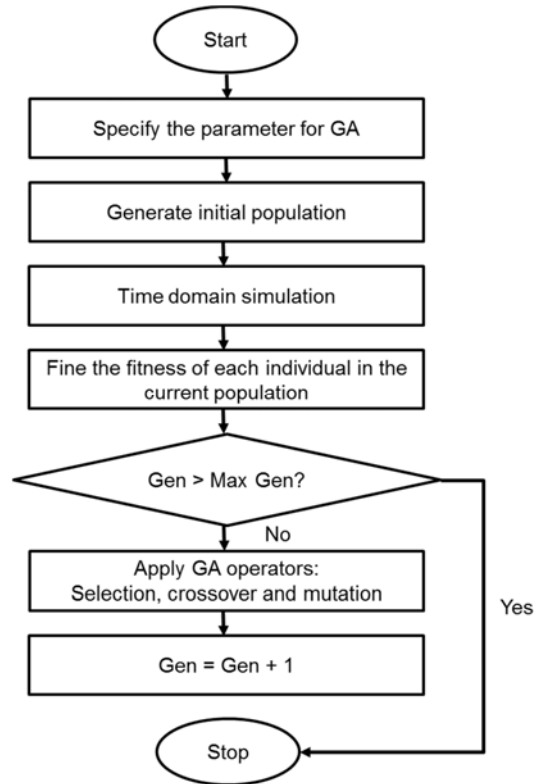


Figure 14. Flowchart of GA

Table 4. Initial Design Variables

Design variable	Initial value
ICE power rating	20 kW
EM power rating	30 kW
Minimum Battery SOC allowed	0.2
Maximum Battery SOC allowed	0.8
Minimum Ultracapacitor SOC allowed	0.2
Maximum Ultracapacitor SOC allowed	0.8

Table 5. Upper and Lower Bound Design Variables

Design variable	Lower bound	Upper bound
ICE power rating	27000	33000
EM power rating	18000	22000
Maximum Battery SOC allowed	0.72	0.88
Minimum Battery SOC allowed	0.08	0.22
Maximum Ultracapacitor SOC allowed	0.72	0.88
Minimum Ultracapacitor SOC allowed	0.08	0.22

Table 6. Fuel Used and Emissions Comparison

Description	Before optimization	After optimization
Fuel used (g)	205.90	192.50
HC (g)	0.5642	0.4545
CO (g)	0.4434	0.3011
NOx (g)	0.7796	0.625
PM (g)	0.000	0.000

Table 7 shows the final values of the six design variables after optimization. It is shown that the rating of the EM is greatly reduced, implying that down-sizing of the EM has been achieved. On the other hand, the ICE is down-sized to a lesser extent.

Table 7. Final design variable values

Design variable	GA
ICE power rating	18 kW
EM power rating	32 kW
Minimum Battery SOC allowed	0.72
Maximum Battery SOC allowed	0.21
Minimum Ultracapacitor SOC allowed	0.72
Maximum Ultracapacitor SOC allowed	0.14

6. CONCLUSION

The results of boat subsystems in terms of ESS current, voltage and output power, and EM speed, torque and power, are within reasonable and expected range. The components of the boat subsystems are correctly sized to achieve the good performance at target velocity. It can be concluded that results of the PPHRB model are correct. Based on the optimization results, the following observations can be made. The fuel used of the PHERB is decreased and the emissions of HC, CO and NOx are decreased as well with the GA optimization. The power rating of the ICE and EM are reduced significantly.

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J. S. Norbakyah received the Bachelor of Applied Science (Physics Electronic and Instrumentation) and Master of Science from Universiti Malaysia Terengganu, Terengganu, in 2009 and 2014 respectively and currently pursuit her Doctor of Philosophy degree in EnergyTechnology in Universiti Malaysia Terengganu. Her main research interest is Electric Vehicle, Hybrid Electric Vehicle, Plug in Hybrid Vehicle, Modelling and simulation and renewable energy.



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