PEMBANGUNAN SISTEM PENDORONGAN KENDERAAN HIBRID DUA ALAM UNTUK OPERASI PENYELAMATAN MARIN

(DEVELOPMENT OF HYBRID AMPHIBIOUS VEHICLE PROPULSION SYSTEM FOR MARINE SAFETY AND RESCUE OPERATION)

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PEMBANGUNAN SISTEM PENDORONGAN KENDERAAN HIBRID DUA ALAM UNTUK OPERASI PENYELAMATAN MARIN

(Kata kunci: Sistem dorongan hybrid elektrik, kenderaan dua alam)

Dalam laporan ini, pembangunan sistem penggerak hibrid elektrik bagi penggunaan kenderaan dua alam dibentangkan. Kenderaan hibrid dua alam – *Amphibious Hybrid Vehicle (AHV)* dibangunkan sebagai pengangkutan yang boleh beroperasi di atas tanah dan air yang berguna untuk pasukan penyelamat dalam operasi menyelamat. *AHV* digerakkan oleh motor elektrik di atas tanah, manakala di atas air, *AHV* dikemudikan oleh enjin pembakaran dalaman – *Internal Combustion Engine (ICE)* dan *ICE* juga berperanan untuk menjanakan tenaga elektrik. Definasi kenderaan hibrid elektrik *(HEV)* adalah menggunakan sumber kuasa daripada gabungan antara motor elektrik dan enjin pembakaran dalaman. Masalah pada kenderaan elektrik *(EV)* yang menggunakan motor elektrik semata-mata sebagai sumber kuasa penggerak mempunyai kelemahan pada sistem penyimpanan tenaga. Laporan ini bertujuan untuk membangunkan satu sistem penggerak hibrid elektrik yang optimum yang mempunyai kebolehpercayaan yang tinggi, minimum dalam penggunaan bahan api, dan mudah untuk dibangunkan. Kaedah kajian yang digunakan adalah; reka bentuk, pembangunan dan analisa kenderaan. Faktor utama yang perlu dipertimbangkan dalam usaha untuk membangunkan sistem penggerak elektrik hibrid adalah kuasa yang diperlukan oleh bateri untuk menghantar kepada motor elektrik bagi menggerakkan kenderaan. Setelah reka bentuk gabungan antara *ICE* dan motor elektrik selesai, maka analisis eksperimen akan dijalankan untuk menentukan kebolehpercayaan dan ketahanan. Keputusan analisis *Matlab Simulink* berdasarkan model matematik dijalankan untuk menentukan kuasa yang diperlukan sebelum proses fabrikasi pembangunan berlaku.

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DEVELOPMENT OF HYBRID AMPHIBIOUS VEHICLE PROPULSION SYSTEM FOR MARINE SAFETY AND RESCUE OPERATION

(Keywords: Hybrid electric propulsion system, amphibious hybrid vehicle.)

In this report, the development of hybrid electric propulsion systems for amphibious vehicle is presented. Amphibious Hybrid Vehicle (AHV) was developed as a transportation that can operate on land and water which is useful for rescue teams in rescuing operations. AHV is driven by an electric motor on the land, while on the water, AHV is propelled by an Internal Combustion Engine (ICE) and ICE also acts to generate the electrical energy. Definition of hybrid electric vehicle (HEV) is a combination of resources from the electric motor and the internal combustion engine. Problems in the electric vehicle (EV) using the electric motor alone as the driving power source has a weakness in the energy storage system. This report aims to develop a hybrid electric propulsion systems that are optimized with high reliability, minimum fuel consumption, and easy to develop. The methodology used in this study is; the design, development and analysis of the vehicle. The main factor to be considered in order to develop a hybrid electric propulsion system is power required by the battery to deliver to the electric motor to drive the vehicle. After the design of combination ICE and electric motor completed the analysis of experiments will be conducted to determine the reliability and durability. The results of analysis *Matlab Simulink* based on mathematical model is conducted to determine the required power before the fabrication process development take place.

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LIST OF SYMBOLS AND ABBREVIATIONS

η_o	Overall efficiency
η_g	Gearbox efficiency
η_d	Driveshaft efficiency
η_a	Wheel efficiency
P	Power
P_w	Power experienced by wheel
P_t	Required mechanical power
P_{b-m}	Real power needed from battery to electric motor
F_{ad}	Aerodynamic drag
F_{rr}	Rolling resistance force
F_{hc}	Gradient force
F_{la}	Acceleration force
F_{te}	Total traction force
ρ	Air density
C_d	Drag coeffiecint
A	Vehicle frontal area
v	Velocity
μ_{rr}	Rolling resistance coefficients
m	Mass
m_v	Vehicle mass
m_r	Rider mass

g	Gravity acceleration
θ	Angle
a	Acceleration
r	Wheel raduis
ICE	Internal Combustion Engine
EV	Electric Vehicle
HEV	Hybrid Electric Vehicle
AHV	Amphibious Hybrid Vehicle
DC	Direct Current
AC	Alternating Current
CO_2	Carbon Dioxide
DOF	Degree-of-Freedom
PM	Permanent Magnet
BLDC	Brushless Direct Current (Motor)
VRLA	Valve-Regulated Lead-Acid
NiMH	Nickel-Metal Hydride
Li-Ion	Lithium-Ion
NiCd	Nickel-Cadmium
UPS	Uninterruptible Power Supplies
MCB	Miniature Circuit Breakers

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CHAPTER 1

INTRODUCTION

PROJECT BACKGROUND

Hybrid vehicle means combination of two or more power source to increase the overall efficiency (Ogawa et al, 2003). The types of hybrid can be classified based on driveline configuration. There are three common types of hybrid design configuration which are series, parallel, and series-parallel.

Although further improvements on vehicle fuel economy since the last 40 years has been done, the average efficiency in the use of gasoline ICE normal operation is only at 15%. While other 85% is lost to the environment as engine heat, exhaust gas heat, aerodynamic drag, rolling resistance of the tires, losses at the driveline and during braking (Germen, 2003). Addition of an electric motor and electric energy storage from ICE can increase diversity of efficiency significantly, depends on the system design.

Common features of most hybrids that improve fuel economy are:

(i) Idle stop

The average vehicle idle time is around 20% of the total driving operation. During this time, turning off the engine can reduce the fuel consumption by 5 to 8%

(Germen, 2003). While during others time, fuel can be saved by turning off the engine when the vehicle is under deceleration, thus CO2 emissions is not released. The idle stop is possible because restarting the engine happen at very low engine speed. The mix of air-fuel is combust at crank speed of 400 rpm. (Ogawa et al, 2003)

(ii) Regenerative braking

During deceleration or braking driving phase, the system will absorb the braking energy and store it in an energy storage device such battery or other components for future use, and it is also helps in charging the battery (Halderman, 2009).

(iii) Power-assist

The electric motor gives additional power to the ICE when the vehicle is accelerated. Assistance from the power-assist module can reduce the size of the engine and improve the fuel efficiency without reducing the overall performance of the vehicle. Application of power-assist in Toyota Prius shows that the performance of 1.8cc ICE is comparable to 2.4cc performance with power-assist (Toyota, 2012).

(iv) Engine efficiency

The ICE efficiency is low during low speed and low load operation. Therefore, to increase system efficiency during this condition, the electric motor can be used as alternative power supply. Hence, fuel consumption and emission is zero at this time.

PROJECT OBJECTIVES

The objectives of the project are:

1. To design the electric hybrid propulsion system for amphibious vehicle.
2. To optimize the parameter of the propulsion system for maximum power delivery.

3. To provide tehnical information for amphibious electric hybrid propulsion system.

PROJECT SCOPES

The scopes of the project are as follows:

1. For objectives #1
   - Benchmark the current electric hybrid systems use in vehicle.
   - Select the suitable propulsion system concept for land and water operation.
2. For objective #2
   - Run multiple hybrid components configuration to get minimum power loss value.
   - Test suitable parameter setting to get maximum power from hybrid system.
3. For objective #3
   - List out optimum technical specifications including components and its configurations for amphibious hybrid propulsion system.

CHAPTER II

MODEL DEVELOPMENT

DEVELOPMENT PROCESS

In development of the hybrid electric propulsion system, the following considerations need to be adhered:

i. Design of hybrid configuration.
ii. Power requirement.
iii. Component selection and arrangement.
iv. Vehicle size.

The first two criteria are very important parameters in order to design a hybrid electric propulsion system. Apart from that, we also have to make assumption of the following:

i. Vehicle moving in constant velocity without acceleration.
ii. There is no energy loss from ICE.

Design process

Firstly, to design the hybrid electric propulsion system is to come up with a power flow planning in the AHV. A series hybrid configuration type is applicable in the vehicle as the propulsion system. The power flow plan is presented in the Figure 1.

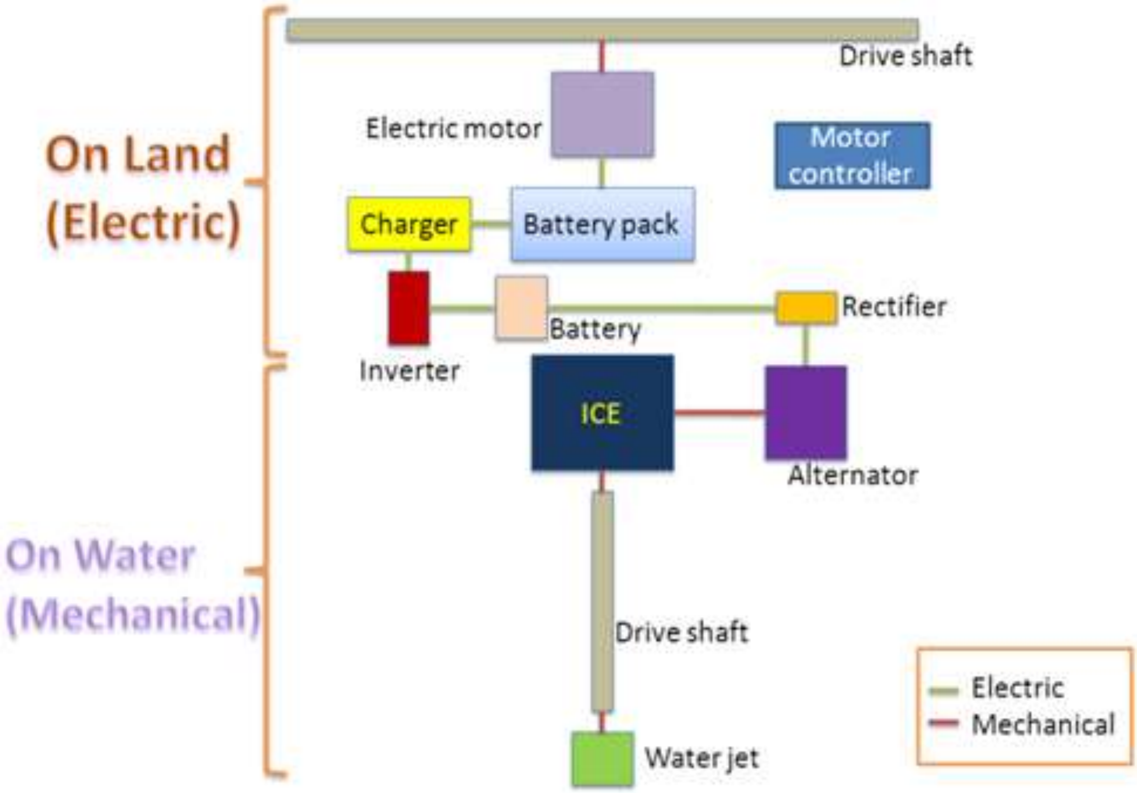

Figure 1 Planning of the power flow in a AHV.

Determining Hybrid Configuration

The AHV hybrid system in Figure 1 consists of seven main components as correlation in the hybrid system of vehicle. When the ICE is running, the alternator that be linked to the crankshaft of ICE will generate the electricity according to the rotation of the crankshaft. The increase speed of crankshaft rotation will increase the production of Alternating Current (AC). Then, the regulator will regulate the unstable rectified AC to the steady at 12Volt of direct current (DC). The 12Volt DC from regulator is recharged the 12 Volt batteries which is used as a power bank. Next, the inverter will amplify the 12Volt DC to the 240Volt DC. The amplified current is then use to run the charger. Charger is use to charge the 60Volt DC battery pack that is required by the electric motor to operate. AHV also come with plug-in charging system to charge power bank as an alternative to ICE charging system.

Both power sources have specific operation environment. On the water surface, AHV is propelled by water jet which is connected to ICE driveshaft. While on the land, AHV is driven by the tyre which is connected to the drive shaft that powered by the electric motor.

The factors that determine the amount of the power from batteries which can transmit to motor electric are: tractive force. It is a summation of aerodynamic resistance force, rolling resistance force, hill climbing force, and acceleration force (Rozaini, 2011). As shown in Figure 2, the vehicle with mass, *m* moving at velocity, *v* on the slope with an angle, θ should overcome all the opposing force.

Table 1 Common value of C_d.

	C_d
Sport car, sloping rear	0.2-0.3
Saloon, stepped rear	0.4-0.5
Convertible, open top	0.6-0.7
Bus	0.6-0.8
Truck	0.8-1.0
Motorcycle and rider	1.8
Sphere	0.47
Long stream-lined body	1.2

Determining the tractive force

Based on the mathematical model of vehicle as shown in the Figure 2, aerodynamics force is a friction force acting on the body surface area with the air when the vehicle is on the move. The corresponding mass density of air may be taken as $1.25\, kg.m^{-3}$ (Rajamani, 2006). The common value of drag coefficient C_d is determined from the Table 1 (Carvill, 2003). Rolling resistance force is due to the friction between tyre and the road surface. The typical value of rolling coefficient μ_{rr} is 0.015 (Laminie & Lowry, 2003). Hill climbing force is required for vehicle to move along incline road. Base on Newton's Second law of motion, the inertia force is increasing if acceleration is increase. Therefore, the tractive force is increasing proportional to inertial force. As mentioned earlier in previous section, vehicle will move on constant velocity. This is to simplify the analysis as the vehicle is in equilibrium condition due to summation of all forces is zero.

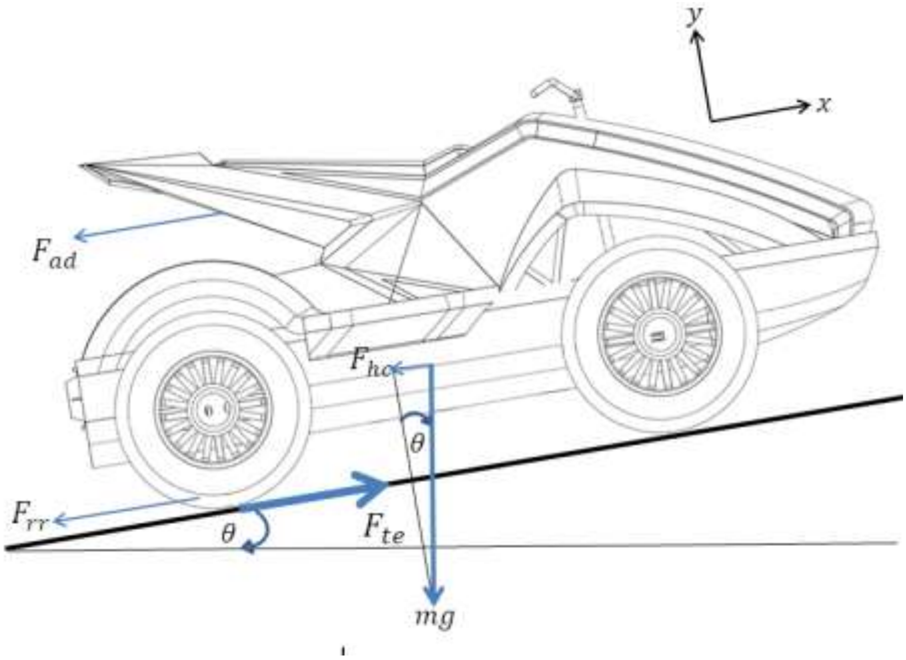

Figure 2 Mathematical model of vehicle.

The following equations are derived to develop the mathematic model for power calculations.

The aerodynamics resistance force:

$$F_{ad} = \frac{1}{2}\,\rho\, C_d\, A\, v^2 \tag{1}$$

The rolling resistance force:

$$F_{rr} = \mu_{rr}\, m_t\, g \tag{2}$$

Hill climbing force:

$$F_{hc} = m_t\, g\, \sin\theta \tag{3}$$

Inertial force:

$$F_{la} = m\, a \tag{4}$$

Total tractive force:

$$F_{te} = F_{ad} + F_{rr} + F_{hc} + F_{la} \tag{5}$$

Power required by batteries for motor electric:

$$P_{b-m} = (F_{te} \times gear\ ratio) + \frac{1}{\eta} \tag{6}$$

Determining power

Assuming that vehicle does not stop until the fully charged batteries is exhausted. The required power of batteries to operate the electric motor at any given constant velocity can be calculated using Equation (6). The power analysis is done for each constant velocity ranging from 0 km/h to 40 km/h with different gradient of $0^o, 5^o, and 10^o$.

CHAPTER III

ANALYSIS RESULTS

POWER ANALYSIS

The analysis is focus only on electric motor and the result of analysis is determined by equations (1) to (6). The equation parameter is shown in Table 2. From Figure 2, the frontal area of vehicle is calculated as stated in Table 2. From Table 1, there is no common value of drag coefficient for this type of vehicle, so the value is assumed as in Table 2. Total of mass is $273.2\ kg$ where the mass of rider is to be assumed with typical weight around $60\ kg$. The vehicle is assumed moving on incline road surface gradient of 0^o, 5^o and 10^o degrees.

Table 2 Assumption and parameter.

Parameter	Value	Parameter	Value
$\boldsymbol{Density\ of\ air, \rho}$	$1.25\ kg.m^{-3}$	$Mass\ of\ vehicle, m_v$	$213.2\ kg$
$\boldsymbol{Drag\ Coefficient, C_d}$	1.3	$Mass\ of\ rider, m_r$	$60\ kg$
$\boldsymbol{Surface\ are, A}$	$0.98\ m^2$	$Efficiency, \eta$	0.98
$\boldsymbol{Gravity\ acceleration, g}$	$9.81\ m.s^{-2}$	$Gear\ ratio$	$^{14}/_{60}$
$\boldsymbol{Rolling\ Coeffient, \mu_{rr}}$	0.015		

With all parameters and assumptions, the result for analysis on power required for vehicle is shown on the graph in Figure 3. The analysis is conducted by using Matlab Simulink Analysis and the block diagram is shown in appendix.

Figure 3 show that the required power of the vehicle to move at any constant velocity is absolutely differences. Power required by battery is proportional with the vehicle speed. Therefore, the speed of the vehicle is depends on the capacity of the power bank. According to the graph, when the vehicle is move on a flat road at speed of 35 km/h, the battery need to supply the power of $1200W$ to the electric motor. By using the same battery power, if the vehicle move along the slope of 5^o, the vehicle can speed up to 16 km/h. The speed of vehicle is up to 9.2 km/h when vehicle move along 10^o of slope.

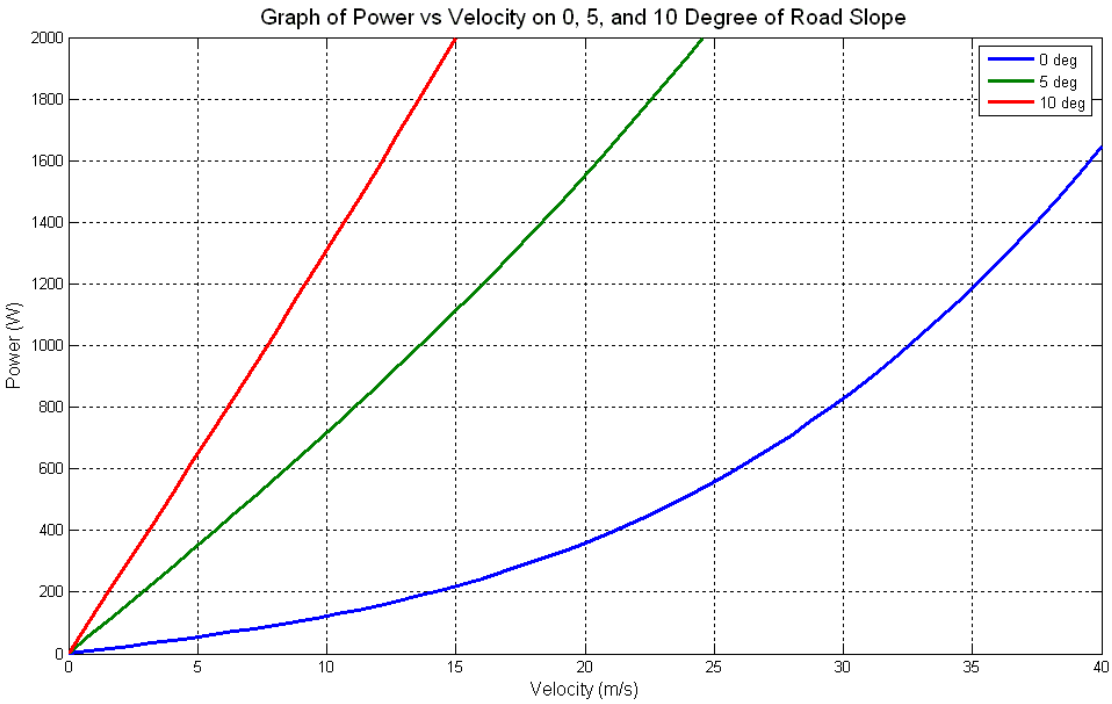

Figure 3 Graph of Power vs. Velocity on 0, 5, and 10 Degree of Road Slope.

The result shows that the power requires are proportional to the vehicle speed and the climb angle. The selection of battery sizing and performance is based on the maximum power required to move the vehicle on flat surface which is 1600W.

CHAPTER IV

FABRICATION PROCESS

FABRICATION OF THE HYBRID ELECTRIC PROPULSION SYSTEM

The next step of this research is the fabrication of the hybrid electric propulsion system. The hybrid electric propulsion system was fabricated by installing the 150cc ICE which is used as a power source for water jet propulsion and it is also use to generate electricity by using the alternator that is built-in inside the engine. AHV is installed with Brushless DC motor with 1kW to 3kW of rated power. Brushless DC Motor is more efficient, more compact and lightweight (Germen, 2003). Lead Acid with Nano Gel technology is used as battery pack for the vehicle. Lead Acid is cheaper compared to Lithium-Ion or Nickel-Metal Hydride and this type of battery is suitable for mild level of hybrid. Five of batteries is used which is 12V, 20Ah each make the total of voltage is 60 Volt. Motor controller with 60Volt of working voltage is used to control the voltage and current supply to electric motor. Throttle voltage for motor controller is 1.2 Volt to 4.3 Volt and the maximum current through motor controller is 70 Ampere. An intelligent charger with 240V is installed into the vehicle. As shown in Appendix, the components are mounted to the chassis of the vehicle. The component placement follows the suitability of the chassis and the component function. The complete diagram of the process is shown in an Appendix.

CHAPTER V

CONCLUSIONS

CONCLUSIONS

In this paper, the development process of the hybrid electric propulsion system is properly demonstrated. It started with proper power planning, then the components integration and finally system testing and analysis. Maximum 3kW rated power of the electric motor capable to propel the vehicle more than 40 km/h. However due to safety factor, the maximum speed of the vehicle is limited to 40 km/h. The installation of electric motor really assists in reduction of fuel consumption and vehicle emission.

RECCOMENDATIONS

Several recommendations are stated here to improve the propulsion system developed:

1. Analysis on the hybrid vehicle model on overall speed with variety load both on simulation and experimental.
2. Analysis on the maximum distance actual vehicle can go until battery depleted.
3. Complete analysis of the vehicle while on the water. In house water test bed facility need to be develop for this experiments.
4. Analyze the hybrid performance using other hybrid configurations.
5. Analysis on power management.
6. Analysis on vehicle life cycle.