A conceptual design of main components sizing for UMT PHEV powertrain

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Abstract. This paper presents a conceptual design of main components sizing for Universiti Malaysia Terengganu plug-in hybrid electric vehicle (UMT PHEV) powertrain. In the design of hybrid vehicles, it is important to identify a proper component sizes. Component sizing significantly affects vehicle performance, fuel economy and emissions. The proposed UMT PHEV has only one electric machine (EM) which functions as either a motor or generator at a time and using batteries and ultracapacitors as an energy storage system (ESS). In this work, firstly, energy and power requirements based on parameters, specifications and performance requirements of vehicle are calculated. Then, the parameters for internal combustion engine, EM and ESS are selected based on the developed Kuala Terengganu drive cycle. The results obtained from this analysis are within reasonable range and satisfactory.

1. Introduction
Along with the common goal of reducing fuel consumption and resulting emissions compared to classical vehicles with internal combustion engine (ICE) for vehicles, the hybrid electric vehicles (HEVs) are increasingly popular as the most promising solution to energy crisis and urban air pollution [1]. In order to obtain a better fuel economy and vehicle performance, the design and sizing of its powertrain components are important [2, 3]. This paper introduces a method for the powertrain component sizing of a series-parallel Universiti Malaysia Terengganu plug-in hybrid electric vehicle (UMT PHEV) [4, 5]. In the design of HEV, it is important to identify proper component sizes [6-8]. This study focuses on the impact of real driving cycle, most daily trips demand. Figure 1 shows schematic illustration of the proposed series-parallel UMT PHEV powertrain.
2. **UMT PHEV parameters, specifications and power requirements**

To develop the UMT PHEV powertrain, calculations of the vehicle energy and power requirements are based on the parameter, specifications and performance requirements. Table 1 lists the typical parameters, specifications and performance requirements of a vehicle of this type.

| Parameters and specifications | Values |
|------------------------------|--------|
| Vehicle configuration        | Series-parallel |
| Vehicle class                | Midsize |
| Vehicle mass                 | 1360 kg |
| Aerodynamic drag coefficient | 0.26   |
| Coefficient of rolling resistance | 0.01 |
| Frontal area                 | 2.57 m² |
| Wheel radius                 | 0.282 m |
| Air density                  | 1.2 kg/m³ |
| Gravitational acceleration   | 9.81 m/s² |
| Performance requirements     |        |
| Maximum speed                | Over 80 km/h |
| EV range                     | 54 km   |

The power required, \( P_{\text{req}} \) for a vehicle as shown in figure 2 is calculated as

\[
P_{\text{req}} = P_{\text{aero}} + P_{\text{roll}} + P_{\text{grade}} + P_{\text{accel}}
\]

where \( P_{\text{aero}} \) is a power to overcome aerodynamic drag which is the present by the standard aerodynamic equation that includes the density of air \( (\rho) \), the drag coefficient of the vehicle \( (C_d) \), the frontal area of the vehicle \( (A) \) and the velocity\( (v) \). \( P_{\text{roll}} \) is a power to overcome rolling resistance which the product of the vehicle mass \( (m) \), the gravitational acceleration due to gravity \( (g) \), the rolling resistance \( (C_n) \), the grade angle of the road measured from the horizontal plane \( (\theta) \) and velocity. \( P_{\text{grade}} \) is a power for ascending which is product of the vehicle mass, the gravitational acceleration due to gravity, the sine of the grade angle and velocity. Finally, \( P_{\text{accel}} \) is a power for acceleration is merely product of the mass of the vehicle, acceleration \( (a) \) and \( v \) is velocity.
3. **Main components sizing**

Based on the vehicle power requirements for steady state velocity, the main components of the UMT PHEV powertrain were sized.

3.1. **Electric Machine (EM)**

The power requirement of the electric propulsion motor is determined by the maximum speed and the maximum gradient at this speed. The maximum gradient is 5%. The designed maximum speed is assumed as 130 km/h. All calculations are undertaken with maximum mass. To achieve 130 km/h with 5% gradient, the propulsion motor power requirement is:

$$\text{PEM} \ (5\%, \ 130 \ \text{km/h}) = 61.27 \ \text{kW}$$

Motor size and cost may be reduced if the speed demand is relaxed. If the vehicle is designed to run at 90 km/h it will still get the requirements, but allowing for a smaller propulsion:

$$\text{PEM, continuous} = \text{PEM} \ (5\%, \ 100 \ \text{km/h}) = 40.75 \ \text{kW}$$

3.2. **Internal Combustion Engine (ICE)**

The ICE requirements are determined by the average power requirements in the series UMT PHEV concept. Cruising at 110 km/h, the maximum velocity is assumed to define the average power in the worst case scenario. The continuous ICE output power requirement is:

$$\text{PICE, continuous} = \text{PEM} \ (0\%, \ 110 \ \text{km/h}) = 14.18 \ \text{kW}$$

The electric output is 14 kW with an estimated efficiency of 85%, the mechanical input power has to be 20 kW. This is the minimum continuous ICE power requirement.

$$\text{PICE, continuous} = 20 \ \text{kW}$$

![Vehicle Power Requirement for Steady State Velocity](image)
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 at 50 km/h in pure electric driving mode. The average velocity is about 50 km/h. In a simplified calculation, an average of 50 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 50 km/h is:

\[ \text{PEM (0\%, 50 km/h)} = 2.01 \text{kW} \]

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

\[ \text{E}_{\text{battery, min}} = \frac{50 \text{ km}}{50 \text{ km/h}} \times \frac{2.01 \text{ kW}}{0.6} = 3.35 \text{kWh} \]

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.

\[ \text{P}_{\text{battery, max}} = 1.5 \times \text{PEM, continuous} - \text{PICE, continuous} = 46.95 \text{kW} \]

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:

\[ \text{E}_{\text{battery, }} = \frac{\text{P}_{\text{battery, max}}}{3 \times h} = 15.65 \text{kWh} \]

4. Selected components parameters and specifications

The selected main components of UMT PHEV powertrain for steady state velocity, which are EM, ICE and ESS based on each component specifications and requirements during the sizing process are list in table 2.

| Component | Specifications          |
|-----------|-------------------------|
| ICE       | 1.5L, 57kW @ 5000rpm    |
| EM        | 50kW AC induction motor  |
| Battery   | Li, 10kWh, 28Ah         |

5. Results and discussions

The analysis on the influence of different drive cycles on the EM, ICE and ESS components that make up the overall structure is carried on the UMT PHEV powertrain using Kuala Terengganu (KT) drive cycle, which is shown in figure 3. The KT dive cycle end at 1049 s covering a distance of km with an average speed of 20.67 km/h and maximum speed of 61.47 km/h.
The main components sizing for KT drive cycle are listed in Table 3 based on the UMT PHEV power requirements as illustrated in figure 4.

Table 3. Components Sizing For KT Drive Cycle.

| Component | Requirement |
|-----------|-------------|
| EM        | 62.7 kW     |
| PEM (62 km/h) | 62.7 kW     |
| PEM, continuous = PEM (41 km/h) | 40 kW       |
| ICE       | 40 kW       |
| ICE, continuous = PEM (30 km/h) | 31 kW       |
| ESS       | 40 kW       |
| ESS, min  | 33.3 kWh    |
| PESS, max | 13.5 kW     |
| EESS      | 40.5 kWh    |

Figure 3. The KT drive cycle.

Figure 4. UMT PHEV power requirement for KT driving cycle.
6. Conclusions
To design an optimal power management vehicle in terms of all electric drive performance and energy efficiency is sizing and selecting the UMT PHEV powertrain main components is the most important task. According to vehicle parameters, specifications and performance requirements, the results of an individual component that make up the overall structure of the UMT PHEV powertrain are within reasonable and expected range using the different drive cycles.

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