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Development Of The Energy Management Strategy For A Hybrid Tricycle

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Abstract

The purpose of this research is to develop an energy management strategy for a hybrid tricycle. The hybrid tricycle has two wheels at the front and one wheel at the rear. The front wheels are driven by in-wheel motors and the rear wheel is driven by an engine power train. The transmission of the engine power train is a Continuous Variable Transmission (CVT) and a final gear. The engine power train is that on the KYMCO Downtown scooter. By doing this, motorcycle manufactures can upgrade their motorcycles to hybrid tricycles easily. From the engine fuel consumption map, one can learn that engine usually has worse performance in low power zone than that in high power zone. Thus, the idea for the energy management strategy design is to activate the motor when the driver required power is low and to activate the engine when the driver required power is high. Simulations show that the fuel consumption rate of the hybrid tricycle is 26.28 km/L and the fuel consumption rate of an engine tricycle is 20.2 km/L. This shows that about 30% of the fuel can be saved with the developed hybrid tricycle.

Keywords:Hybrid tricycle, Energy management strategy, Vehicle dynamics simulation

1 Introduction

Due to the reason of energy shortage and global warming, Electrical Vehicle (EV) has been a solution to solve the problem among international societies. Among the different types of electrical vehicles, Hybrid Electrical Vehicle (HEV) integrating motor and engine powers is the most successful one. This is because it can provide similar performance as the conventional Internal Combustion Engine (ICE) vehicle in terms of cruising range and power. Also, by an appropriate control strategy, the engine operation can be confined at a fuel efficient zone such that the fuel consumption and emission can be reduced [1].

Currently, many HEVs have been introduced to the market, which includes TOYOTA Prius, FORD Prodigy, Mercedes-BenzBlueHYBRID etc.. Most of these vehicles are middle size and are not suitable for crowded urban area. Thus, to develop a small size hybrid vehicle for urban commuter is the goal of this project. Also, with the concern of market feasibility, a low cost vehicle is desired. Thus, the vehicle uses a KYMCO mass production motorcycle engine such that the cost of the vehicle can be minimize.

The HEVs can be simply divided into two groups; serial HEV and parallel HEV. Configurations of these two groups of HEV are shown in Figure 1. For the serial HEV, the engine drives a generator to charge the battery and the vehicle is propelled by the motor. Examples of serial HEV are in [2]. On the other hand, there are three types of parallel HEV. For the first type, the motor and the engine share the same shaft. For the second type, the motor and engine are coupled by a coupler. Finally, for the third type, the front wheels and rear wheels are driven by motor and engine individually and the configuration of the hybrid Tricycle of this project is the same as the third type of parallel HEV. A typical case of parallel HEV is the TOYOTA Prius [3].

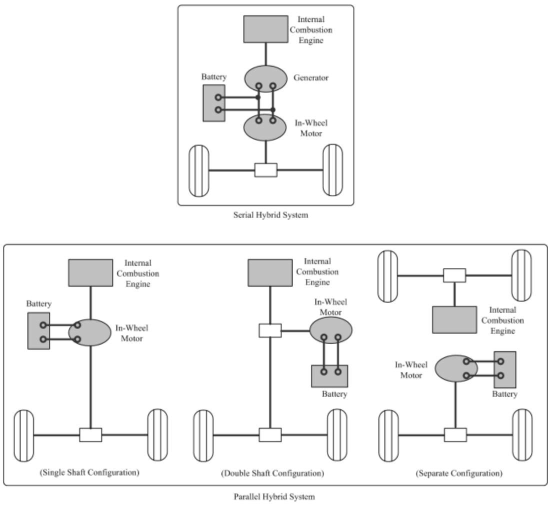

Figure 1: Configurations of the HEVs

2 System Configuration And Specification

Figure 2 shows the configuration of the hybrid tricycle. It shows that this tricycle has two seats and has two wheels at the front and one wheel at the rear. The front wheels are driven by in-wheel motors and the rear wheel is driven by an engine power train. The transmission of the engine power train is a Continuous Variable Transmission (CVT) and a final gear. A generator is coupled to the output shaft of the engine to charge the battery. The batteries are located at the bottom of the chassis to lower the center of gravity.

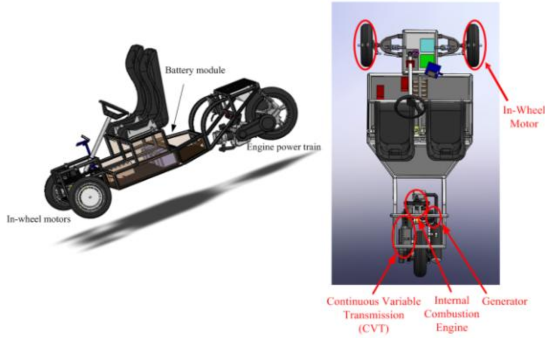

Figure 2:configuration of the hybrid tricycle

The total weight of the vehicle including two passengers is 510 kgw is about the size of a mini car. The motor performance curve and engine brake specific fuel consumption (BSFC) map are obtained using testing benches and the results are shown in Figure 3 and Figure 4. Due to the need of the energy management strategy, a fuel efficient variation curve is located and is plotted in Figure 4. The above results are then summarized into a specification table as shown in Table 1.

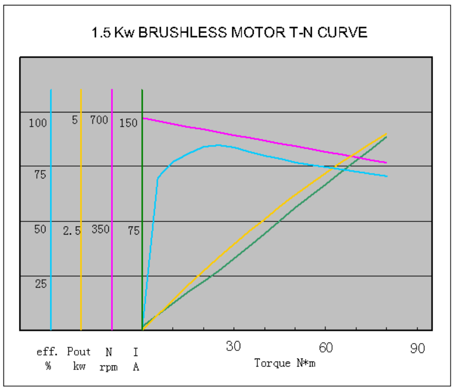

Figure 3:in-wheel motor performance curve

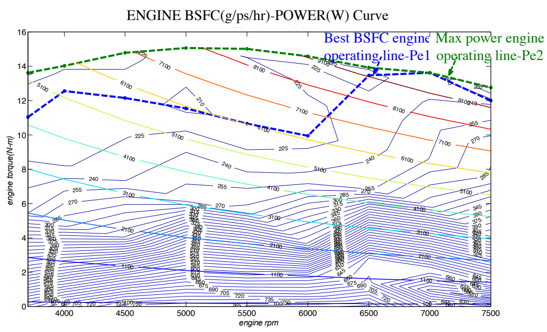

Figure 4: engine BSFC map

Table 1:Specifications of motor and engine

Motor specification

parameters	value
weight	25(kgw)
Rated voltage	48V
Rated power	1.5KW
Rated torque	22N-m
Rated speed	640rpm
Maximum power	4.5KW
Maximum torque	80.20N-m
Maximum speed	680rpm
Maximum efficiency	84.8%

Engine specification

parameters	value
Maximum power	10KW
Maximum torque	15N-m
Maximum speed	7500rpm
CVT gear ratio	0.886~3.176
Final gear	8.644

3 Energy Management Strategy

From the engine BSFC map, one can learn that engine usually has worse performance in low power zone than that in high power zone. Thus, the idea for the energy management strategy design is to activate the motor when the driver required power is low and to activate the engine when the driver required power is high. Thus, motor is activated to meet $P_m = P_{req}$ if $P_{req} < P_{th}$ where P_{req} is the driver required power, P_m is the motor output power, P_{th} is a threshold obtained from the engine fuel consumption map to distinguish the high fuel consumption zone from the low fuel consumption zone. On the other hand, if $P_{req} > P_{th}$ and the battery State Of Charge (SOC) is greater than the desired level of SOC , namely $\mathrm{SOC_d}$, only the engine is activated to drive the vehicle. However, if SOC is low, engine is activated to drive the vehicle and to drive the generator to charge the battery simultaneously. When the SOC is two low (i.e. $\mathrm{SOC_d} - \mathrm{SOC} > \mathrm{SOC_{th}}$ where $\mathrm{SOC_{th}}$ is a designated threshold), engine is activated to continuously charge the battery to $\mathrm{SOC_d}$ even the driver required power is in low power zone. A dummy variable, δ, is used for this purpose. In other words, if continuous charging is desired, δ is set to be 1 until SOC reaches $\mathrm{SOC_d}$ and then is set back to 0. When the SOC is low but within a tolerance, the charging mode is activated only when $P_{req} > P_{th}$. In the charging mode, at every instance, engine is controlled to operate at an optimal point. The optimal point is chosen from the engine fuel map in terms of fuel efficiency and is related to engine speed (i.e. $p_e(\omega_e)$). In this situation, $p_{req} = p_e(\omega_e) + p_{gen}$ where p_{gen} is the generator output power. Finally, for two levels of SOC (i.e. $0.1 \geq \mathrm{SOC_d} - \mathrm{SOC} \geq 0$ and $\mathrm{SOC_{th}} \geq \mathrm{SOC_d} - \mathrm{SOC} \geq 0.1$), two such groups of optimal points are chosen from the fuel consumption map (i.e. $p_{e1}(\omega_e)$ and $p_{e2}(\omega_e)$ and $p_{e2}(\omega_e) > p_{e1}(\omega_e)$ for the same engine speed). The proposed energy management strategy is shown in Figure 5.

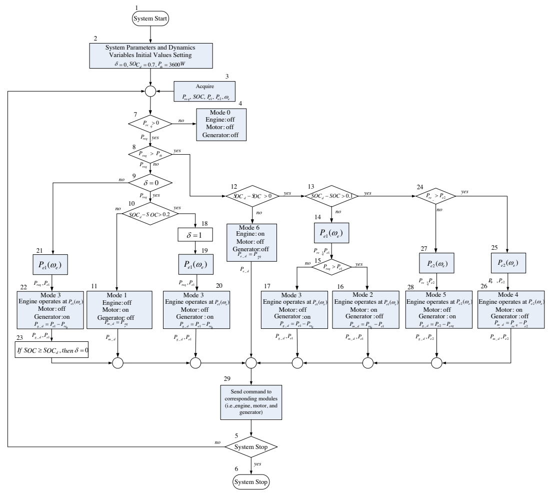

Figure 5: energy management strategy

4 Simulation Results

Figure 6 shows a simulation result of the tricycle dynamics. This simulation assumes that the driver handles the vehicle to follow ECE40 speed pattern perfectly. In this simulation, $\mathrm{SOC_{th}} = 0.2$, $P_{th} = 3600\,\mathrm{W}$, and the initial SOC is 0.6. One can see that, in this driving pattern, most of the required power is below 3600 W. Thus, motor is activated most of the time, the charging mode is activated rarely, and the SOC drops continuously down to the threshold level of $\mathrm{SOC_d} - \mathrm{SOC} = \mathrm{SOC_{th}} = 0.2$. Then, δ is set to be 1 and the charging mode is activated continuously up to $\mathrm{SOC_d}$. Then, δ is set back to 0, the continuous charging mode is deactivated. After that, SOC drops again as depicted previously. It can be shown that a small variation range of SOC can be achieved by choosing appropriate P_{th} and $\mathrm{SOC_{th}}$ values. Finally, a comparison of fuel consumption between engine vehicle and hybrid vehicle is shown in Table 2, which shows that a dramatic improvement can be reached.

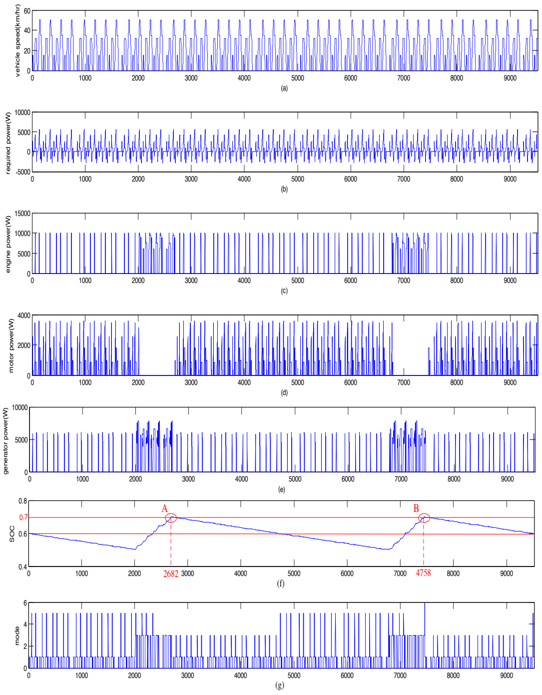

Figure 6:(a)ECE40 (b)required power (c)engine power (d)motor power (e)generator power (f)battery SOC (g)operation modes

Table 2: Comparison of fuel consumption between hybrid vehicle and engine vehicle

Type of vehicle \ Fuel consumption	Traveling range per liter of gasoline(Km/L)
Hybrid vehicle	26.3 Km/L
Engine vehicle	16.1 Km/L

5 Conclusion

The purpose of this research is to develop an energy management strategy for a hybrid tricycle. In this research, a rule base algorithm is adopted for the development of the energy management strategy for its easiness to design. The idea for the energy management strategy design is to activate the motor when the driver required power is low and to activate the engine when the driver required power is high. Simulation results show that the fuel consumption rate of the hybrid tricycle is 26.3 km/L and the fuel consumption rate of an engine tricycle is 16.1 km/L. This shows that about 60% of the fuel can be saved with the developed hybrid tricycle.

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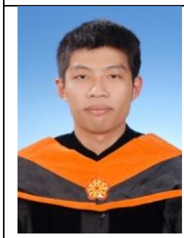

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