A new energy control strategy for a through the road parallel hybrid electric motorcycle

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Abstract— **Design and simulation of a Through The Road (TTR) Parallel Hybrid Electric Motorcycle (HEM) with continuous variable transmission (CVT) is described in this paper. The model of a Parallel Hybrid Electric powertrain in ADVISOR is modified for simulation of it. To achieve a better fuel economy and less emission, the internal combustion engine (ICE) should operate at high efficiency regions. In order to increase the efficiency, the ICE should not operate low torque values. Therefore, a new energy control strategy is proposed to improve it while the ICE is ON. In this new strategy, the extra torque of the ICE is absorbed by the electrical machine.**

Keywords-Hybrid Electric motorcycle; TTR powertrain; control strategy; ADVISOR.

I. Introduction

Technological advances make the human life more comfortable, but on the other hand, these advances cause many problems and damages to the human life environment including pollutions. The engine emission is one of several main issues that pollute our environment. Nowadays, a global plan is needed to reduce the environmental pollutions. Using electric, and hybrid electric vehicles, and other less polluted fuels such as ethanol are among the solutions to reduce the emissions or not to let them to increase. The hybrid technology and hybrid electric vehicles are put forward as a new argument and because of its specifications, it is expected that this technology becomes more and more popular [1].

Motorcycles are usually used in urban areas. Urban transportation requires a low output power and it causes the incomplete combustion and more air pollution because of the low permissive speed and many cycles of braking and movement [2]. On the other hand, Motorcycle emission is much more than passenger cars [3]. Therefore, many researches all over the world have been trying to solve this problem by offering different methods such as hybrid concepts. Until now, only a few companies produced some experimental models of the Hybrid Electric Motorcycle (HEM). For example, Yamaha has introduced a hybrid motorcycle that was named Gen-Ryn in the 39th Tokyo motorcycle exhibition [4]. ECycle Company in the United States has produced another hybrid motorcycle model named EC1 with Brushless motors [5]. Kuen-Bao Sheu et al designed and implemented a parallel HEM transmission that continuous variable transmission (CVT) which has low efficiency in low speeds, does not operate in low speeds [6]. Chia-Chang Tong et al changed a conventional motorcycle to parallel HEM by attaching an electric motor via gearbox to the rear wheel of the motorcycle [7]. Pierluigi Pisu et al studied on efficiency and energy management of different topologies of hybrid electric vehicles [8].

In the Through The Road (TTR) construction of hybrid electric vehicle (HEV) electric machine is coupled on one axle and engine is coupled on the other axle. Therefore, the power from the engine to the electric machine can be transmitted via the road and wheels when the vehicle is moving. This is the easiest construction that a conventional vehicle can be converted to a hybrid vehicle [9]. Matthew Young et al converted a 2005 Chevrolet Equinox to a TTR parallel HEV and introduced a control strategy for that [10].

In this paper, at first a Through The Road (TTR) parallel HEM with CVT and lithium batteries is designed. The proposed HEM has an electric machine in the front wheel and can run in the only electric mode, to avoid running the ICE at low powers. Then to simulate it, the Parallel Hybrid Electric powertrain of the ADVISOR software is modified to a TTR powertrain model.

Finally, a new energy control strategy for parallel hybrid electric motorcycles is introduced to reduce the fuel consumption and emission. The simulation is carried out based on this control strategy and compared with the conventional motorcycle.

II. Design of a TTR HEM

A. *Desired motorcycle targets*

The desired motorcycle should be able to achieve the top speed of 80 Km/h, and the acceleration time of 10 seconds to reach the speed of 60 Km/h from zero.

The motorcycle should also be able to cruise at the speed of 20Km/h in the road with grade of 10%.

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B. Resistive Powers and body coefficients

The motorcycle should overcome resistive forces and at the same time maintain the required acceleration. The required power to overcome the resistive forces can be estimated from the following equations [11].

Rolling resistance power:

$$P_r(v) = f_r . m_{\max} . g . v \qquad (1)$$

Air drags power:

$$P_{air}(v) = \tfrac{1}{2} . c_d . A_f . \rho . v^3 \qquad (2)$$

Gradient power:

$$P_{grad}(grad, v) = m_{\max} . g . v . \sin\left(\tan^{-1}\left(\frac{grad}{100}\right)\right) \qquad (3)$$

The motorcycle body coefficients are assumed to be as follows:

Air drag coefficient	$c_d = 0.5$
Frontal area	$A_f = 0.62\ m^2$
Tire rolling coefficient	$f_r = 0.009$
Mass	m = 185 kg
Maximum mass	$m_{max} = 250$ kg
Wheel radius	$R_d = 0.25$ m
Average mech. Eff.	$\eta_{mech}=0.5$

C. Internal combustion engine

Internal combustion engine (ICE) should be able to propel the motorcycle alone at the speed of 80 Km/h in a flat road. Total power of the ICE to cruise at constant speed of *v* is calculated by (4).

$$P_{ICE}(grad, v) = \frac{P_r(v) + P_{air}(v) + P_{grad}(grad, v)}{\overline{\eta}_{mec}} \qquad (4)$$

For this speed, the required power from the ICE should be about 4.2 kW. However, the power that the ICE has its highest efficiency is about %75 of its maximum power. Therefore, the maximum power of the ICE should be around 5.5 kW.

D. Electric motor

Electric motor in the hybrid motorcycle should supply part of the required power for acceleration. The estimated required power for acceleration from zero to 60 km/h in 10 seconds can be calculated by (5).

$$P_t = \frac{\delta_m m_{\max}}{2\eta_{t,m} t_a}\left(V_f^2 + V_b^2\right) + \frac{2}{3} f_r . m_{\max} . g . v_f + \frac{1}{5} c_d . A_f . \rho . v_f{}^3 \qquad (5)$$

where V_b is the base speed that is the start of flux weakening region in the electric motor. It is assumed to be around 20 km/h.

δ_m is the mass coefficient that its value is assumed to be around 1.

$\eta_{t,m}$ is the efficiency of the electric motor transmission and is assumed to be around 0.9 because of the TTR powertrain.

The power demand for acceleration is calculated 4.6kW from (5). If the maximum power of 3.9kW is produced by the ICE and is applied to rear wheel, the electric motor should supply the rest that is 700W. The efficiency of the electric motor transmission $\eta_{t,m}$ is 0.9, therefore the electric motor should be able to supply 800W. The electric motor can be overloaded at acceleration time with the factor of 2. So, an electric motor with the power of 400 W is needed.

The electric motor is assumed an in-wheel motor in the front wheel. As it does not have a gearbox and its base speed is 20 km/h, it cannot produce a noticeable torque at high speeds.

E. Batteries

The batteries should supply the power for the electric motor during acceleration. If motor efficiency is considered to be 90%, the power that the batteries should supply, is about 900 W. The Lithium batteries discharge current rate is 10C. The voltage of the batteries is around 50; therefore the capacity of the batteries should be around 1.8 Ah.

III. SIMULATION

At first, a conventional motorcycle with CVT is simulated with ADVISOR. The values of common variables between conventional motorcycle and the designed hybrid motorcycle are the same. The simulation for ECE driving cycle is executed, and the efficiency of the ICE operating points during time is shown in figure 1.

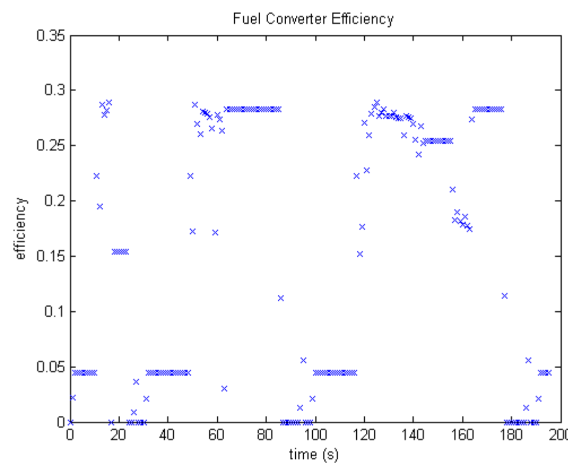

Figure 1 Efficiency of the ICE operating points during time in ECE cycle

Then, to simulate the designed TTR parallel HEM with CVT and lithium batteries with ADVISOR software, the model of a Parallel Hybrid Electric powertrain is modified for simulation of the TTR powertrain. The original block diagram of ADVISOR model is presented in Figure 2. In this model, the speed and the torque of the ICE and the electric motor are combined in the “torque coupler” block diagram. Then, the output of it inputs “CVT gearbox”, goes to the “final drive”, and the “wheel and axle” block diagrams respectively. It is not a proper model for the TTR powertrain and the simulation results are not correct.

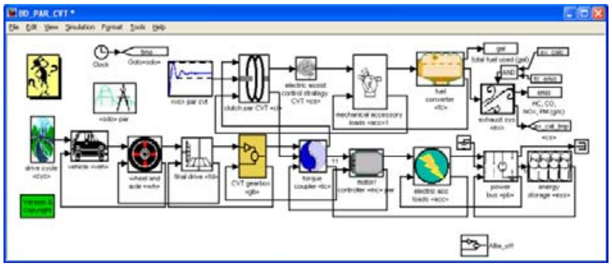

Figure 2. The original block diagram of ADVISOR model for parallel hybrid electric vehicle with CVT

To modify this model, the "CVT gearbox" and the "final drive" block diagrams are placed after the "clutch par CVT" block diagrams and the output of the "final drive" and the output of "motor controller" are combined in the "torque coupler" block diagram. Then, the output torque of that and the speed go to the "wheel and axle" block diagram. The new model is shown in Figure 3. In the "torque coupler" block diagram that models three coupled gears, the gears assumed to be the same, so the speeds of the wheel and the electric motor and the final drive are assumed the same.

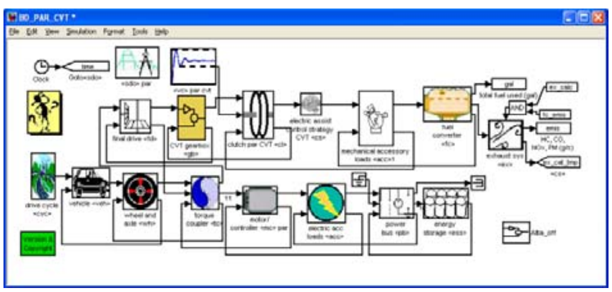

Figure 3. The modified block diagram of ADVISOR model for TTR parallel hybrid electric vehicle with CVT

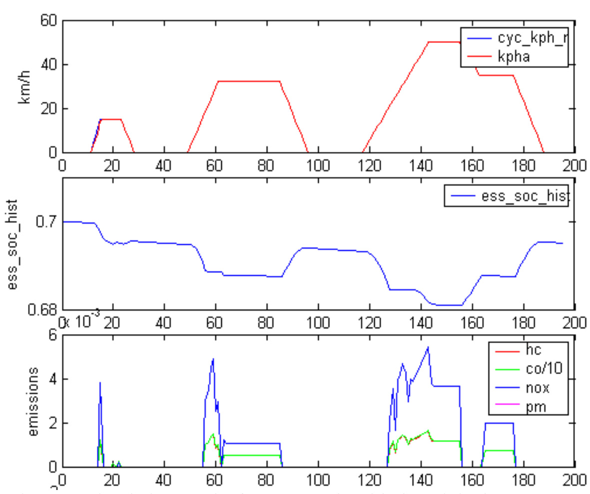

Figure 4. Simulation results for ECE cycle with the original ADVISOR control strategy

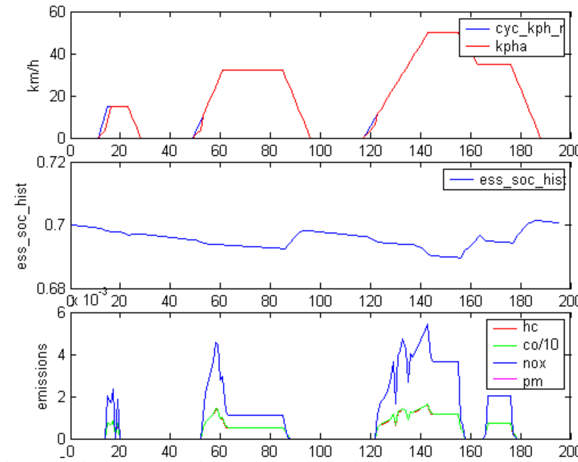

Figure 5. Simulation results for ECE cycle with the new proposed control strategy

A modification that is made in ADVISOR block diagrams is due to changing of the operation mode. When speed or demanded power changes a little around constraints, the mode may be change. For example if it is operating on the electric mode, the engine is off, and the demanded power increases, the mode changes to engine mode and it should be ON in the new mode. If the value of the demanded power is about the power limits, then with a little change in that the mode should be changed. This will lead to frequent engine turn ON and OFF that is not desirable. In some cases, e.g. at time 61 sec in Figure 4, the engine is turned off for one second only and then it is turned ON again. To solve this problem, a hysteresis is applied on mode changing, so that the mode will not change until the change command comes three times. It prevents the frequent turn ON and off of the engine. As shown in Figure 5, the number of turn ON and off of the engine is three times less than the numbers in Figure 4.

A. *Energy Control strategy*

In the brake mode, the regenerative braking is applied, so the electric motor absorbs part of the kinetic energy of the motorcycle.

During the acceleration and cruising modes, the energy control strategy is so that if the requested power is low, only the electric motor propels the motorcycle. If the requested power is between two certain constraints, i.e. 0.2 and 0.8 of the ICE maximum power, the ICE propels the vehicle. In this case the electric machine becomes generator and charges the batteries if it is needed. The maximum charge power is 300 watt. The control strategy is so that the battery state of charge (SOC) becomes about 0.7. Therefore, the charge power requested from the ICE equals 300× (0.7 - SOC). Hence, if the SOC is greater than 0.7, the charge power is negative and it means that the electric machine helps the ICE and supplies a part of required power, and if SOC is less than 0.7, the electric machine absorbs a part of the ICE power and charges the battery.

If the requested power is high, both the ICE and the electric motor propel the motorcycle at low speeds and only the ICE propels the motorcycle at high speeds.

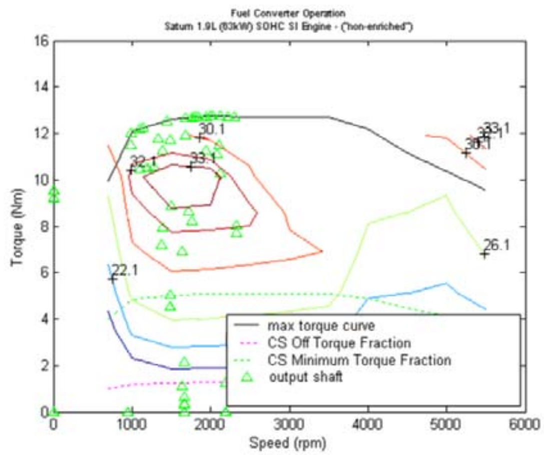

Figure 6. Operating points of ICE in torque-speed map with the original ADVISOR control strategy

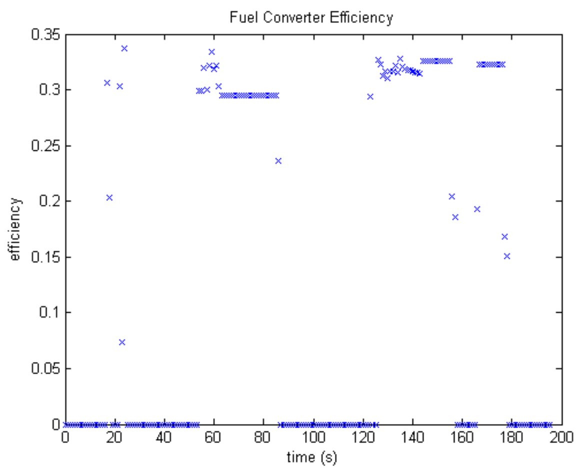

Figure 7. Efficiency of ICE operating points during time with the original ADVISOR control strategy

The simulation and the result in the ECE driving cycle is shown in Figure 4 based on the ADVISOR control strategy. As shown in Figure 6, in this control strategy, there are some operating points that the ICE outputs torque is low. Therefore, the efficiencies of those operating points are low, as shown in Figure 7.

In the new control strategy, the ICE is not allowed to produce low torques in order to operate in the high efficiency regions. Hence, if a low torque is requested, the electric machine will becomes generator to maintain a higher operating point and the energy of that will charge the batteries. This means that the ICE will produce torques that are higher than the requested torque. Part of that torque is absorbed by the electric machine and part of that will goes to the wheels

Figure 8 and 9 show the simulation results based on the new control strategy. As it is clear, the operating points are moved to higher efficiency regions.

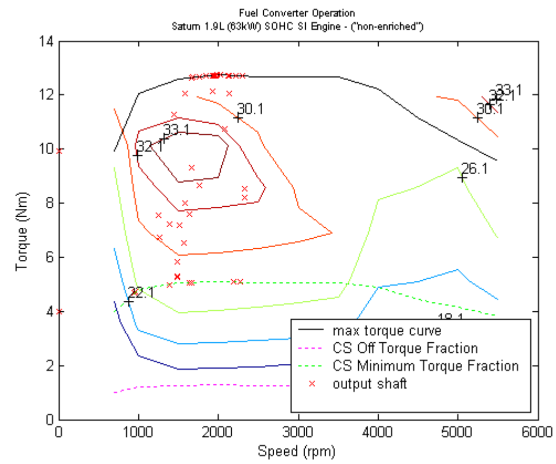

Figure 8. Operating points of ICE in torque-speed map with the new proposed control strategy

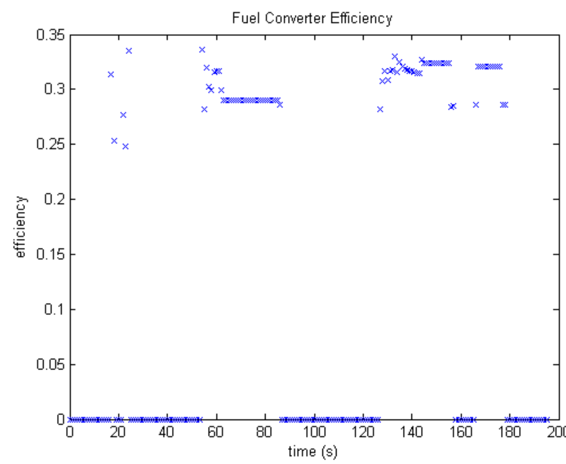

Figure 9. Efficiency of ICE operating points during time with the new proposed control strategy

B. Comparisons

By comparing Figure 6 and Figure 8, it is obvious that the ICE operating points are all above a certain torque. Comparison between Figure 7 and Figure 9 also shows that the efficiency of the ICE operating points are all above 22% and all low efficiency operating points are omitted. Consequently, the overall efficiency of the motorcycle is improved.

C. Results

Based on the simulation program, the following results for three type of motorcycles (1- Conventional, 2- Hybrid with the original ADVISOR control strategy, 3- Hybrid with the new proposed control strategy) are compared in Table I.

Table I: Simulation results for three types of motorcycles

Description	Unit	Conventional motorcycle	HEM with original ADVISOR control strategy	HEM with new proposed control strategy
Acceleration time to reach 60 km/h	sec	12.1	6.9	6.9
Gradeability with speed 20.9km/h	%	7.4	11	11
The highest speed	km/h	87.3	95.8	95.8
Fuel consumption	liter/ 100km	2.67	1.26	1.25
Hydro-carbon emission	g/km	4.25	2.31	2.3
Carbon monoxide emission	g/km	18.56	10.08	10.04
Nitrogen oxides emission	g/km	0.218	0.123	0.123
The ICE average efficiency	%	23.57	31.32	31.41

It is apparent that the HEM fuel consumption and emission reduced about 50% compared to the conventional motorcycle. It is also obvious that the new control strategy slightly improves the ICE average efficiency and the fuel consumption, and reduced the emission a little. Moreover, it maintains the acceleration, the gradeability, and the maximum speed. Although, there is not a significant improvement, but the engine is not working at no load conditions as before. Furthermore, the number of turn ON and OFF of the ICE is reduced a lot that is very important in practical applications as it takes a few seconds for the ICE to turn on.

IV. Conclusion

In this paper, a TTR Parallel Hybrid Electric Motorcycle with continuous variable transmission is designed, and simulated with the ADVISOR software. The model of Parallel Hybrid Electric powertrain in ADVISOR is modified for simulation of TTR powertrain. To achieve better fuel economy and less emission, the engine should not operate at low efficiency regions. When the engine output torque is low, the efficiency is bad. Therefore, the control strategy is such improved that when the engine is ON, it produces a minimum torque at least, and the electric machine absorbs additional torque and saves it in batteries.

References

[1] M.Ehsani, E.Gao, S.E.Gay, A.Emdadi, "Modern Electric, Hybrid Electric, and Fuel Cell Vehicles", CRC press, 2005, pp. 1-4.

[2] M. Shafiepour, H. Kamalan, "Air Quality Deterioration in Tehran due to Motorcycles" Iran Environment Health Sci., Eng., Vol. 2, No. 3, 2005, pp. 145-152.

[3] A.N. Bleijenberg and J.M.W. Dings, "*European transport: emission trends and policy responses*", Center for Energy Conservation and Environmental Technology, p583, 2009.

[4] 39th Tokyo Motor Show Yamaha Motor Display Models. Available: http://www.yamaha-motor.co.jp/global/news/2005/10/05/tms.html

[5] E-cycle Company website. Available: http://www.ecycle.com/docs/eCycle%20Hybrid%20March%208,%202007%20Machine%20Design.pdf

[6] Kuen-Bao Sheu , Tsung-Hua Hsu, "Design and implementation of a novel hybrid electric motorcycle transmission", Elsevier, Applied Energy, vol 83, 2006, pp. 959–974.

[7] Chia-Chang Tong, Wu-Shun Jwo, "An assist-mode hybrid electric motorcycle", Elsevier, Journal of Power Sources, vol 174, 2007, pp. 61–68.

[8] Pierluigi Pisu, Kerem Koprubasi and Giorgio Rizzoni,"Energy Management and Drivability Control Problems for Hybrid Electric Vehicles", 44th IEEE Conference on Decision and Control, and the European Control Conference 2005, Seville, Spain, December 12-15, 2005.

[9] Josef B. Kejha, Sagar N. Venkateswaran, "Low cost inversion of any internal combustion vehicle into hybrid electric vehicle", US patent: US20080236910, October 2, 2008.

[10] Matthew Young, G. Marshall Molen, David Oglesby, Kyle Crawford, Kennabec Walp, Ron Lewis, Christopher Whitt, Stephen Phillips,"The Design and Development of a Through-the-Road Parallel Diesel Electric Hybrid", IEEE Vehicle Power and Propulsion Conference, 2007.

[11] Dennis Doerffel, "Testing and Characterisation of Large High-Energy Lithium-Ion Batteries for Electric and Hybrid Electric Vehicles, Ph.D. Thesis", March 2007, School of Engineering Sciences, Faculty of Engineering, Science and Mathematics, University of Southampton.