SIMULATION OF CONVENTIONAL PASSENGER VEHICLE

USING ENGINE MAP WITH DIFFERENT CONDITION

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June 2017

This dissertation is submitted to
Universiti Sains Malaysia
As partial fulfilment of the requirement to graduate with honors degree in
BACHELOR OF ENGINEERING (MECHANICAL ENGINEERING)

School of Mechanical Engineering
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DECLARATION

I hereby declare that the work reported in this thesis is the result of my own investigation and that no part of the thesis has been plagiarized from external sources. Materials taken from other sources are duly acknowledgements by giving explicit references.

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ACKNOWLEDGEMENT

I address this acknowledgement to my supervisor in guiding me, into finishing this final year project. Also, to my family and friends directly or indirectly help me in this project.

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ABSTRAK

Kajian ini, membuat model simulasi berbalik mengenai kenderaan di Malaysia (Perodua Myvi) dengan bersertakan model penukar tork. Simulasi ini juga dilaksanakan dengan kondisi berbeza. Kondisinya adalah pembawakan biasa, bergerak dan berhenti, peralihan naik gear awal, peralihan naik gear lewat, peralihan gear turun awal dan peralihan gear turun lewat. Pembandingan data daripada kondisi pembawakan biasa dan bergerak dan berhenti, dibuat antara simulasi dan eksperimen. Pembandingan dilaksanakan menggunakan kitaran pembawakan yang sama dan juga mengunakan perisian Matlab untuk menjalankan model. Kitaran pembawakan di ambil dua kali pada masa yang berlainan di sekitar kawasan negeri Kedah dan Pulau Pinang. Dapatan kajian ini adalah kondisi bergerak dan berhenti memberi pengunaan bahan api ekonomi yang paling rendah. Dengan purata perbezaan data simulasi dan eksperimen adalah 14.4% data ini boleh digunapakai.

ABSTRACT

This study simulates a backward facing mathematical model of vehicle in Malaysia (Perodua Myvi) with the presence of torque converter model and the simulations is running on different condition. The conditions are normal driving; start and stop; early down shift; early up shift; late down shift and late up shift. Normal driving and start and stop condition for fuel consumption results from the simulation are compared to the experimental fuel consumption of the same vehicle run on the same drive cycle, to verify the mathematical model for Perodua Myvi that was simulated by using Matlab. The drive cycles data are gathered twice at different times of the day based on city roads and high way in the state of Penang and Kedah, Malaysia. The best fuel economy found is the control strategy of start and stop. Simulation and experimental results are comparable, with the average percentage difference of 13.3 % for the vehicle model.

INTRODUCTION

In Malaysia, the number of vehicle rose great in numbers from 2010 to 2015, the registered number of vehicle recorded by Jabatan Pengangkutan Jalan Malaysia is 20188565 to 26301952 units [1]. With the increase of fuel price, manufacture are trying to develop the most fuel economic vehicle. Thus, the factors that affect the engine performance and fuel consumption, needed to be studied to optimize the overall performance of the passenger vehicle and save fuel. Control strategy is one of the methods to optimize vehicle performance. Thus, this project will find the best control strategy with the minimal fuel consumption.

Every manufactured passenger vehicle have different control system. The control strategy is used to provide optimum driving maneuver, to save fuel consumption and improve overall vehicle performance. Control strategies function is to control the vehicle actuator with sets condition to provide a proper working mechanism for optimization. This control strategies are relayed via the Engine Control Unit (ECU), for example hybrid vehicle will use its motor to accelerate when the vehicle is from stop condition. In theory, normal driving condition of Perodua Myvi the engine will not shutdown when the vehicle stop. One of this project control strategies, is to simulate shut down of the engine when the vehicle stopped. To explain the condition, the torque and engine speed will become zero as the vehicle velocity reaches zero. This is to simulate the engine shut down at standstill. Other control strategies for this project, the gear ratio will be chosen base on the velocity, transmission load and transmission speed, according to the engine limit range for the gear shifting.

The passenger vehicle setup is as shown in Figure 1. Vehicle must encounter four forces (inertial, air drag, road gradient and tire resistance) for the vehicle to move. In the simulation, using the data obtain in the drive cycle speed, acceleration is obtain by finding the difference of two velocity and divide by time from the drive cycle. Thus, force was calculated from the input data. From the forces obtain the torque was derive from it, using the wheel parameter and wheel force. A series of conditions was setup for the selection of gear ratio. After the speed and torque of wheel was obtain and the gear ratio, the all data is translated by the transmission to be the input of the torque converter. Next, the torque and speed at the torque converter input shaft becomes the engine operating conditions. The engine operating conditions are used to estimate the fuel consumption from the engine map. The fuel consumption is then summed up for the entire drive cycle to determine the fuel economy of the vehicle [2].
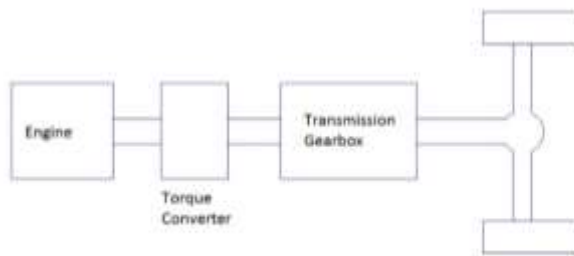
Figure 1 : Schematic diagram of passenger vehicle system

By using MATLAB, the simulation is running with discretised backward-facing. Since, this model have the sampling rate of 10Hz, the time for each point is not 1 second. This means that the drive cycle is divided into discrete time steps spaced of time of 2 points (t_1-t_0). Each time step consists of the average speed and the average acceleration of the vehicle

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at that point. The simulation uses iteration method of each point in the drive cycle to the end (t=n).

METHODOLOGY

SIMULATION

The backward-facing simulation is done by using MATLAB software. The simulation reads the speed data from the drive cycle discretely for each time step (t_1-t_o). This is due to the drive cycle obtain for the start and stop experiment having 10Hz sampling rate. Vehicle model is fed with the average speed and the acceleration from the drive cycle for every time step. From the simulation the torque and speed of wheel was obtain and using the vehicle parameters and the drive cycle. Gear ratio selected is used to determine the engine speed and torque, the gear ratio selection is based on the control strategy set. Engine torque and speed is determine using the gear ratio and the torque converter speed ratio and torque ratio. The fuel consumption is determined using the engine operation (engine speed and torque) interpolate with the engine map of Perodua Myvi [3]. The fuel consumption values at each time step are summed up, and the total fuel consumption of the vehicle operating on the drive cycle, is obtained. Figure 2 shows the visualization of the vehicle modelling.
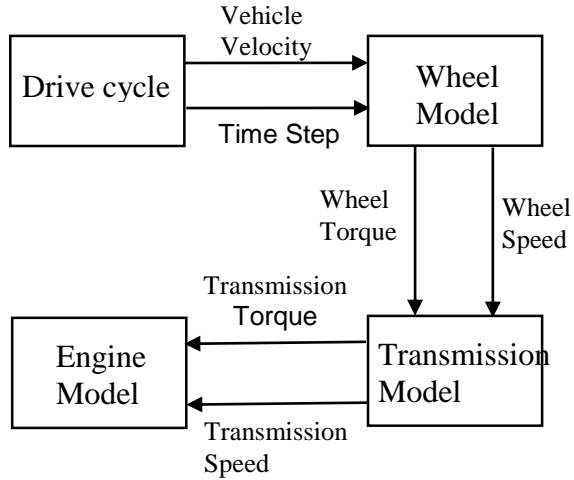
Figure 2 : Schematic diagram of backward- facing vehicle model

SIMULATION EQUATIONS

The vehicle encounters four forces in order for the vehicle to move. The forces are air drag force (F_{drag}), acceleration force (F_{accel}), slope road force (F_{slop}) and rolling resistance force (F_{resist}). Therefore, in order for the vehicle to move, the force at the wheel must be greater than net force for the vehicle. This can be derives using Equation 1.

$$F_{wheel} = F_{drag} + F_{accel} + F_{resist} + F_{slop} \qquad [1]$$

Where F_{wheel} is the wheel driving force.

For air drag force equation,

$$F_{drag} = 0.5 \, \rho \, v^2 \, C_d \, A \qquad [2]$$

Where, ρ is density of air (kg/m^3), v is velocity of the vehicle (m/s), C_d is air drag coefficient and A is frontal area of the vehicle (m^2).

For acceleration force,

$$F_{accel} = m \, a \qquad [3]$$

Where, m is the sum mass of vehicle and the driver (kg) and a is the vehicle acceleration (m/s^2).

For rolling resistance force,

$$F_{resist} = C_r \, m \, g \qquad\qquad [4]$$

Where C_r is the coefficient of rolling resistance, m is the sum of the mass of the vehicle and the driver (kg), and g is the gravity acceleration (m/s2).

For slope road force,

$$F_{slop} = m \, g \, \sin \alpha \qquad\qquad [5]$$

Where m is the sum of the mass of the vehicle and the driver (kg), g is the gravity acceleration (m/s2), and α is angle of slope road (º).

From the total of force, Equation 1, we can derive wheel torque, transmission torque, torque converter and engine torque by using Equation 6, 7, 8 and 9.

For wheel torque,

$$T_{wheel} = F_{wheel} \, R_{tire} \qquad\qquad [6]$$

Where T_{wheel} is the wheel torque (Nm) and R_{tire} is the radius of the tire (m).

For transmission torque,

$$T_{transmission} = T_{wheel} \, / \, G\_ratio \qquad\qquad [7]$$

Where $T_{transmission}$ is the transmission torque (Nm) and G_ratio is the total gear ratio.

For torque converter,

$$T_{converter} = T_{transmission} \, / T\_ratio \qquad\qquad [8]$$

Where $T_{converter}$ torque converter (Nm) and T_ratio is torque ratio for the torque converter.

For the engine torque,

$$T_{engine} = T_{converter} \, / \, \eta_t \qquad\qquad [9]$$

Where T_{engine} is the engine torque (Nm) and η_t is the efficiency of transmission between the engine and the torque converter. After that, engine angular speed need to be found in order to read the engine map for fuel consumption. It can be calculated by using Equation 10, 11, 12 and 13.

For the wheel angular speed,

$$\omega_{wheel} = v / R_{tire} \qquad [10]$$

Where ω_{wheel} is the wheel angular speed (RPM) and v is the velocity of the vehicle (m/s)

For transmission angular speed,

$$\omega_{transmission} = \omega_{wheel} \; G\_ratio \qquad [11]$$

Where $\omega_{transmission}$ is the transmission angular speed (RPM).

For angular speed converter,

$$\omega_{converter} = \omega_{transmission} / \omega\_ratio \qquad [12]$$

Where $\omega_{converter}$ angular speed converter (RPM) and ω_ratio is speed ratio for the torque converter.

For the engine angular speed,

$$\omega_{engine} = \omega_{converter} / \eta_t \qquad [13]$$

Where ω_{engine} is the engine angular speed (RPM) and η_t is the efficiency of transmission between the engine and the torque converter. The speed ratio and the torque ratio is define as equation 14 and 15 [4].

For speed ratio,

$$\omega\_ratio = \omega_{transmission} / \omega_{converter} \qquad [14]$$

For torque ratio,

$$T\_ratio = T_{transmission} / T_{converter} \qquad [15]$$

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Using Equation 16, will can find the fuel economy for the vehicle.

$$Fuel\ Economy\ (km/L) = DT/\ FCT \qquad [16]$$

Where, DT is total distance travelled (km) and FCT is the total volume of the fuel consumed (L). [5]

VEHICLE PARAMETER, GEAR SELECTION AND TORQUE CONVERTER PARAMETER

Vehicle parameter are taken from [3], [5] and the variable is used inside the model to calculate the fuel consumption. Data on vehicle parameter is shown in Table 1. Torque converter parameter was taken from [4] for the torque ratio selection. Table 2 show the data of torque converter.

Table 1 : Vehicle parameter of Perodua Myvi.

Parameter	Symbol		Value
Total gear ratio	G	1st Gear	11.01
		2nd Gear	6.15
		3rd Gear	4.03
		4th Gear	2.81
Tire radius	R_{tire}		0.3556m
Frontal area	A		2.306m^2
Drag coefficient	C_d		0.32
Density of air	ρ		1.225kg/m^3
Density of fuel	ρ_{fuel}		716.0755kg/m^3
Gravitational acceleration	g		9.81m/s^2
Coefficient of rolling resistance	C_r		0.01
Transmission efficiency	η_t		0.85

Table 2 : Torque converter parameter.

Parameter	
Speed ratio	**Torque ratio**
0.00	2.14
0.10	1.99
0.20	1.84
0.30	1.70
0.40	1.56
0.50	1.43
0.60	1.30
0.70	1.18
0.80	1.06
0.85	1
0.90	1
0.95	1
1.00	1

The gear selection is made base from the vehicle speed as shown in Table 3. Gear selection

is optimize using a set of control strategy with respect to engine torque and engine angular

speed.

Table 3 : Gear selection rules.

Vehicle speed (m/s)	Gear
<7.73	1
7.73 to 13.83	2
13.83 to 21.09	3
>21.09	4

Table 4: Gear selection rules for early shift

Vehicle speed (m/s)	Gear
<4.73	1
4.73 to 10.83	2
10.83 to 17.09	3
>17.09	4

Table 5: Gear selection rules for late shift

Vehicle speed (m/s)	Gear
<10.73	1
10.73 to 16.83	2
16.83 to 21.09	3
>21.09	4

CONTROL STRATEGIES

For gear selection it is optimize by using control strategy. The basic rule still apply base on Table 3, the selection was then checked by using the engine torque and engine angular speed. The feedback is used to shift up or down gear when exceeding the engine torque and angular speed. The gear shift up when the engine angular speed exceed 4500 RPM and will shift down when the engine torque exceed 100 Nm. Figure 3 described the flow of data feedback for gear selection control strategy. This was also referred to [6]

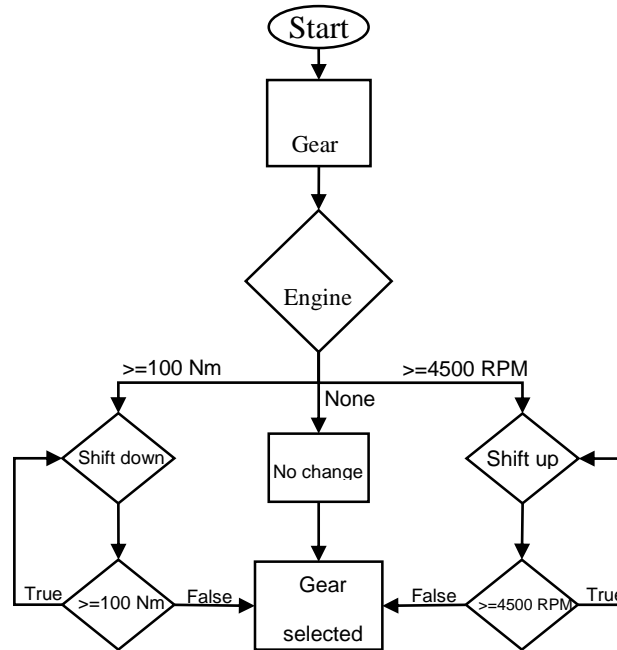*Figure 3 : Algorithm flowchart of gear selection.*

For torque converter, speed ratio and torque ratio selection is made by fixing the converter angular speed at 2250 RPM to replicate average angular speed for normal driving condition, 3000 RPM for engine speed just before gear shift up and 2500 RPM for in between gear shift and normal driving. The torque ratio is interpolated based on the speed

ratio. The control strategy for the torque converter, engine speed will change if the speed ratio exceed value of 1. Figure 4 describe the flow of data feedback for speed ratio selection control strategy.
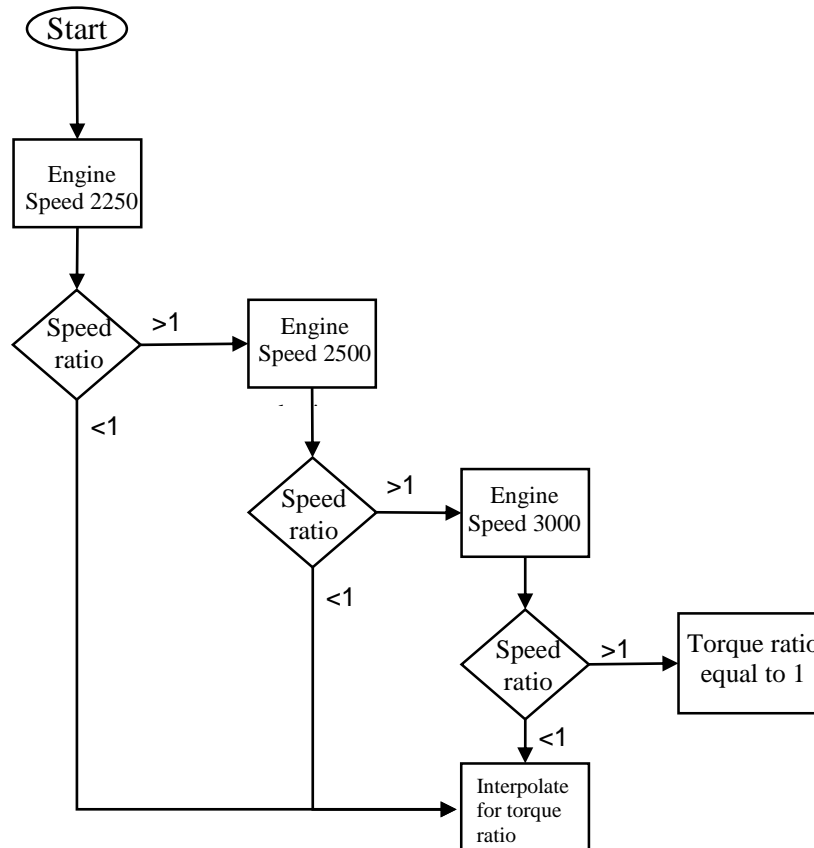
Figure 4 : Algorithm flowchart of ratio selection for torque converter.

For start and stop condition the engine torque and angular speed data change to zero as the vehicle stop (v=0). This is to study the effect of fuel consumption for different control strategies.

For the early shift up, early shift down, late shift up and late shift down. All this condition is controlled by changing the gear selection rule base on Table 4 and 5. By detecting the

acceleration of the vehicle, the condition chose either Table 4 or 5 rule compare to Table 3. Figure 5 show the flow of data for the gear rule selection.

```
            ( Start )
                |
                v
        +---------------+
        |    Vehicle    |
        |  acceleration |
        +---------------+
                |
                v
           /‾‾‾‾‾‾‾\        True    +-------------+
          < Gear set >------------>|  New gear   |
          <requirement>            |  shifting   |
           _____/               +-------------+
                |                          |
             False                         |
                |                          |
                v                          |
        +---------------+                  |
        |Original gear  |                  |
        |  shifting     |                  |
        +---------------+                  |
                |                          |
                v                          |
        +---------------+                  |
        | Use to find   |<-----------------+
        | transmission  |
        |  operation    |
        +---------------+
```
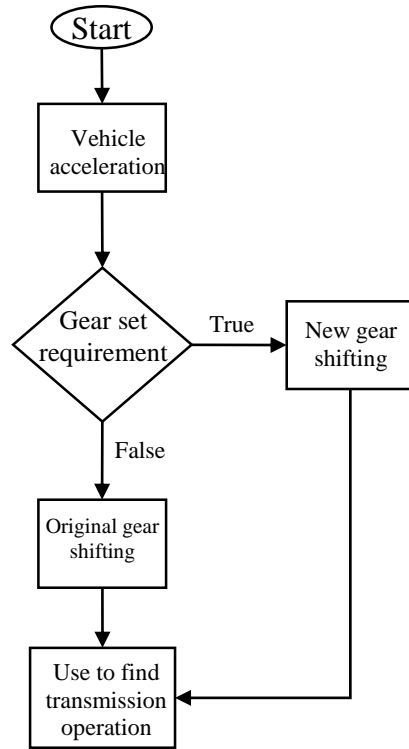
Figure 5 : Algorithm flowchart of control strategies of shifting

EXPERIMENT

FOR MODEL VALIDATION

The validation of the model uses the data from experiment, and methodology is obtain in [5]. This procedure is to find the experimental data for only the validation of model vehicle. The fuel economy was recorded by driving in Alor Star city, Kedah, Malaysia and Perodua Myvi drove over five designated courses. The car was fuelled up and driven over the designated courses. At the end of each course, the fuel tank of the car was filled up again to determine the volume of the fuel was used. This is to calculate the experimental fuel economy.

The drive cycles of five different courses were recorded by using 'My Tracks' android app. The data of five courses are taken twice, at different time of the days. Five drive cycles are derived from city driving conditions. The five drive cycles are also used in the simulations, and the fuel consumption values obtained from the simulations are then compared to the experimental ones.

FOR START AND STOP COMPARISON

For the experimental procedure and data was conducted by other FYP student, it was obtain from [7]. This procedure is to find the experimental data only for the fuel economy different between experiment and model vehicle for start and stop control strategy. The drive cycle was recorded by driving in city Nibong Tebal, Penang, Malaysia (E-city) and Parit Buntar, Perak, Malaysia (F-City). Perodua Myvi drove over designated courses. The drive cycles were recorded by using 10 Hz GPS receiver which hooked up

with Arduino. The time step for each data is 10 Hz, therefore the vehicle model finds the time step for each data.

The recorded data of drive cycle and engine angular speed was recorded using Arduino and connected with OBD-ii cable to the ECU. The data was then put into a model simulation of torque converter, in order to obtain the engine torque. From the engine speed and the engine torque, it was then used on the engine dynamometer test. The test is to find the fuel consumption and fuel economy was calculated from it. The two routes are used in the engine dynamometer, in order to obtain the fuel economy. The fuel economy values obtained from the engine dynamometer are then compared to the simulation done by this project.

RESULTS AND DISCUSSION

MODEL VALIDATION

For the validation of model, the fuel economy simulated is compared to the experiment [5] and the result shown in Table 4. Based on the results, the percentage differences for all drive cycle B3, B4, C5, C6, E9 and E10 are all above 10%. While A1, A2, D7, D8 show difference of less 10%. The highest deviation of data is 30.3% and the best result is 1.1%. There are few factor that effect the data both experiment and simulation.

For the experimental part [5], the amount of fuel consumed is obtained from the fuel volume readings at the fuel station. Meanwhile, the speed data are obtained from the Global Positioning System (GPS). The accuracies of these two measuring methods are unknown. The results are also affected by the fuel density because of the temperature of the surrounding. From the increase of the surrounding temperature fuel density also decreased due to the expansion of the volume. Thus, the volume of fuel needed to fill up the tank until it is full is lower.

For the simulation part, the main factor affecting the results is the torque converter. The torque converter used base from research done by other vehicle. It may not have the same parameter as Perodua Myvi. Vehicle fuel consumption also effect by the vehicle feature such as Variable Valve Timing (VVT). VVT is a feature that will help in saving fuel by adjusting the air intake in the combustion [7]. Moreover, this model cannot simulate back flow at the torque converter. This effect the data when the vehicle decelerate.

Additionally, the simulation does not take into account the accessories that are used in Perodua Myvi, such as a hydraulic power steering pump and an air conditioning system.

START AND STOP COMPARISON

The data obtain from the experiment [7] and the simulation is as shown in Table 5. The difference in the data is significant. For both drive cycle E and F shows different of more than 50%. The highest difference of the data is 126% for drive cycle E. There are several factor that effect the data obtain both experiment and simulation.

For the experiment data, the engine torque is obtained by using simulation. This may affect the torque data due to unknown accuracy of the model. The data of fuel consumption obtain by using engine dynamometer, the data input for the dynamometer maybe inaccurate due to the use of simulation data itself. Moreover, the experiment set up did not use real time fuel consumption in order to calculate the fuel economy.

For the simulation part, the factor is the same as explain in the model validation part.

DIFFERENT CONTROL STRATEGIES

The data of fuel consumption was obtain for each control strategies and shown in Table 6. The start and stop control strategy uses the drive cycle from route F. From the result, the highest fuel economy value that is 13.1217 Km/L. Comparing to the normal drive done by the simulation that is 10.7296 Km/L. Early shift up shows a slightly increase compare to the normal driving and the other control shift in the fuel economy value. There are factor that effect the data for shifting control strategies.

For the shifting control strategies, the main factor that effect it is the control strategy set for the torque converter. The torque converter used only 3 fix engine speed, where in real case the engine speed respond dynamically and not as step function.

Table 4: Comparison of fuel economy between the experiment and the simulation for vehicle model validation.

	No. of drive cycle	Time	Experimental fuel economy (Km/L)	Simulation fuel economy (Km/L)	Differences (%)
A-City	1	Morning	8.168	8.7750	7.4
	2	Afternoon	9.770	9.1463	6.4
B-City	3	Morning	9.767	8.5631	12.3
	4	Afternoon	10.96	8.4568	22.8
C-City	5	Morning	14.03	9.7821	30.3
	6	Afternoon	7.480	8.5124	13.8
D-City	7	Morning	10.18	9.9112	2.6
	8	Afternoon	10.49	10.6092	1.1
E-Highway	9	Morning	12.77	10.2277	19.9
	10	Afternoon	14.74	12.3823	16.0

Table 5: Comparison of fuel economy between the experiment and the simulation for start and stop control strategy

	Fuel economy (Km/L)		
	Experiment	Simulation	Differences (%)
F-City	5.806	13.1217	126
G-City	8.658	13.2628	53

Table 6: Comparison of fuel economy between other control strategy using routes F-City

Control strategies	Fuel economy (Km/L)
Normal drive	10.7296
Start and stop	13.1217
Early shift up	11.5015
Early shift down	10.7635
Late shift up	10.1917
Late shift down	10.6662

CONSLUSION

This study shows the vehicle model can be used with the present of torque converter model and from all the control strategies setup, the control strategy that have the best fuel economic is the start and stop. The other control strategies shows only small changes in the fuel economy compare to normal drive.

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