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Modelling and Control of Hybrid Vehicle

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ABSTRACT

Environmental pollution is one the major issue for entire world. Burning of petroleum and gas in combustion engines of vehicles is one the biggest sources of harmful environmental pollution. To keep in mind this issue, hybrid technology is evolving as one of the latest way to get rid of this problem but obviously it will take much time to remove almost 70% gasoline engines overall in the world. In this study, same sort of issue is discussed. Improvement of fuel consumption in automobile by increasing the number of gears is explained in this paper with graphs. Parallel hybrid electric vehicle is modelled by using Matlab/simulink for 4^{th} and 6^{th} gear automatic transmission. 4^{th} gear transmission is not much fuel economic due to which number of gears are increased up to 6 to improve the fuel economy of hybrid vehicle. The logic behind the increment of gears is also explained very well. Improvement of fuel consumption and mileage of vehicle is presented by theoretical and also by comparing the graphs by using different drive cycles for 4^{th} and 6^{th} gears automatic transmissions.

Keywords: parallel hybrid, automatic gear transmission, Matlab/simulink graphs, Fuel economic. Gear ratio calculation.

1. INTRODUCTION

Fuel is one of the most important requirements in this present world, we need fuel almost in all aspect of life. Transportation and industry are two main places where we need fuel [1]. To decrease the consumption of fuel is only possible when there will be more different ways to get power [2]. Hybrid technology plays very important role at this stage. From last few decades hybrid technology is getting exponentially progress. The idea of this thesis work is to model a hybrid electric vehicle and model different gear transmission [3] model using Matlab and comparing the performance of the HEV on different drive cycles. Recent researches on hybrid vehicle modelling and simulations are referred to in [12], [13], [14], and [15].

First the hybrid electric vehicle designed with a simple gear box and then a 4-speed automatic transmission and then 6^{th} gear automatic transmission [4]. Matlab/simulink is used to model this parallel hybrid electric vehicle. Analysis and investigation of different gear transmission are taking place to get most beneficial and fruitful results for producing much high performance based HEV [5]. Comparison of different transmissions is taken place by using different drive cycles to get improved fuel economy. Section II discussed about the main requirements of the modelling of parallel hybrid vehicle. Section III elaborates theoretical formulations for improved fuel economy while section IV proves the improvement by fuel consumption by graphical representation. And in last section the whole concept of article is summarized.

2. MATLAB MODELING AND SIMULATION OF HEV

This hybrid Electric Vehicle Model is modeled by using Matlab modeling software. Model is divided into different sub models. These submodels perform different tasks according to the requirements. These models are based on mathematical equations [6]. Series and parallel hybrid electric vehicles [7] can be designed with improved fuel consumptions [8]. This thesis based on improvement of fuel consumption using 4th gear to 6th gear transmission so other submodels are explained in brief.
Drive cycle is the first submodel which is directly connected with vehicle model and automatic gear transmission which is finally connected with Hybrid control unit. Fuel tank model, electric system model, and ICE model are connected with HCU from the other side.

2.1 Hybrid Control Unit

The main role of this model is performed by HCU. All commands from requirement end to source end are given and taken by this block. Whatever the demand of torque and speed at the output terminal, HCU distributes the power between [9] electric motor and internal combustion engine (ICE). This unit continuously turn off and turn on the engine and electric motor [10] according to the requirement. So this unit is highly optimized to get most beneficial combination of hybrid sources.

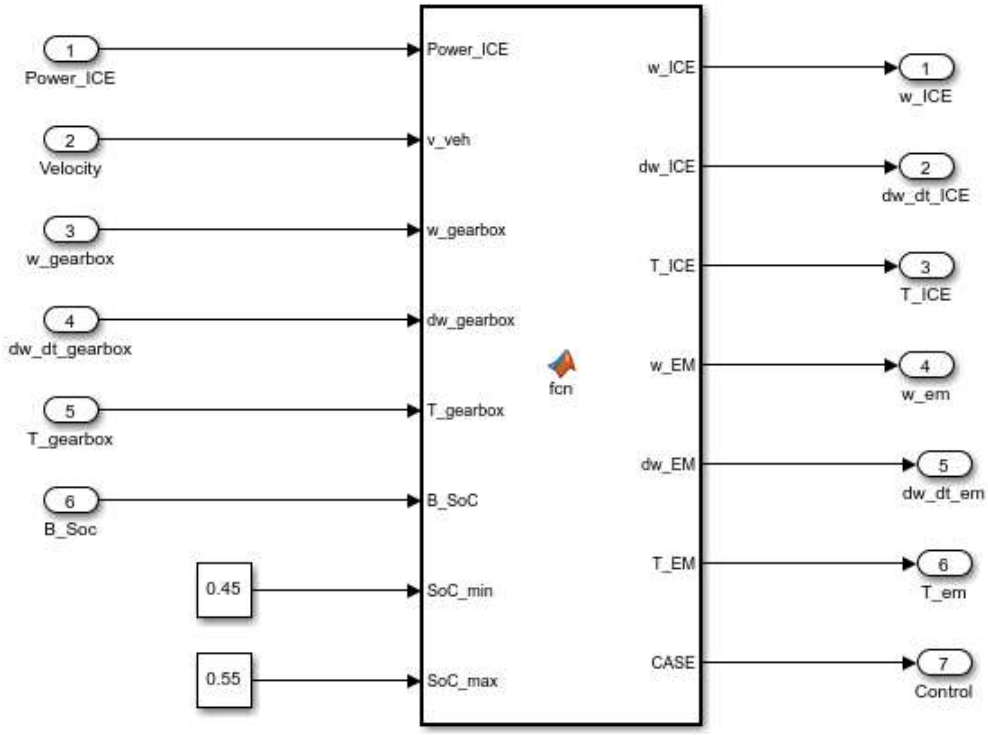

Figure 1. Hybrid Control System Functional box

This is the responsibility of control system that at which time which source needed to use to complete the demand of the torque at required speed. It is divided into several cases but main 2 cases are discussed below to completely explain the function of control block.

2.1.1 Negative torque demand

It is the simplest case when the torque demand is negative.
In case 1, if T_gearbox <= 0
w_ICE = 0
dw_ICE = 0
T_ICE = 0
If the torque demand is below zero mean negative then it will not take any power from internal combustion engine. It means vehicle will consume zero fuel when negative torque is demand.

if B_SoC<SoC_max (1)
w_EM = w_gearbox
dw_EM = dw_gearbox
T_EM = T_gearbox

At the same point if the state of charge of battery is shown below maximum charge which could be 99% of battery charge then it will charge the battery.
In case when:
w_EM = 0
dw_EM = 0
T_EM = 0
If the state of charge of battery is shown equal or above maximum charge which could be 99% of battery charge then it will not charge the battery. In this condition both electric motor and engine will show off for producing power.

2.1.2 Low torque with limited vehicle velocity

T_lim2 = torque limit = 80 Nm
V_lim2 = telocity limit = 40 m/s
if v_veh<=v_lim1 (2)
if T_gearbox <= T_lim1 (3)
if B_SoC<SoC_min

In this case when required torque is lower than torque limit "Eq.(2)" with limited vehicle velocity and at the same time the state of charge of battery is lower than minimum SOC then following condition will be fulfilled to run vehicle.
w_ICE = w_gearbox
dw_ICE = dw_gearbox
T_ICE = T_gearbox
If B_SoC>SoC_min (4)

Only internal combustion engine will give power to vehicle and at the same time it will not take or give any power to electric motor. This is the point at which hybrid vehicle save its fuel, because at this point "Eq.(4)" when battery is enough more than minimum

then vehicle will totally run by electric motor. And no ICE power is used at this stage. Similar to the same case,

If T_gearbox <= T_lim2 (5)
B_SoC>=SoC_max (6)

If required torque is little "Eq.(5)" bit higher in demand and battery is more than maximum, then it will only get power from ICE because ICE has enough power to fulfill the requirement and electric motor remain turned off during this situation.

2.2 Transmission of Hybrid Vehicle

This part of the vehicle is responsible to transmit power to wheel according to the demand of it. In this part gears are used to drive vehicle efficiently. In this case 4th gear transmission is used initially to explain the gear shifting and gear ratio of transmission system.

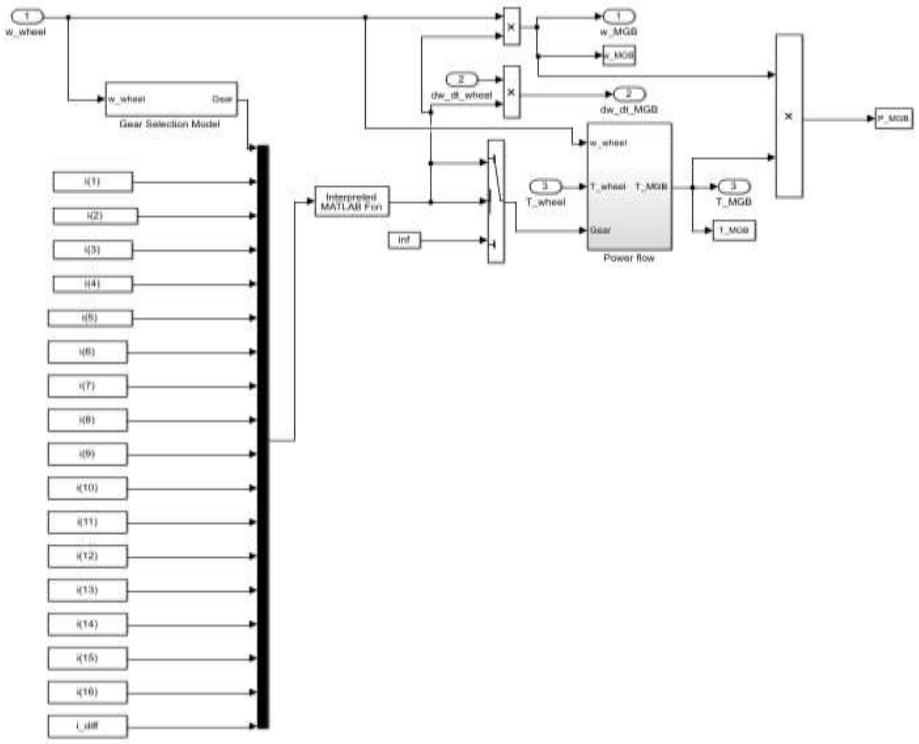

Figure 2. Automatic transmission and selection of gear

From above model it can be seen that selection of the gear is depend upon the speed of the wheel which is interpreted in Matlab function box from where the selection of the gear is selected. Acceleration of the fly-wheel is the combination of acceleration of wheel and the selection of gear from interpreted matlab function.
In the same way, velocity of the fly-wheel depends upon the combination of speed of wheel with same gear selection method. The selection of the torque on the fly-wheel is quite difficult process to explain as it passes through different options and selection methods.

2.3 Modeling of Combustion Engine

Combustion Engine gets fuel from fuel tank and with the help of ignition and piston it generates power which is mechanical movement and then this mechanical power is used to drive shaft of the car. According to the required power hybrid control system decides that how much power is utilize from combustion engine because at lower torque and lower speeds only electric motor can drive vehicle in that situation combustion will remains off. But at higher torque demand engine works more but hybrid control system divides power very wisely.

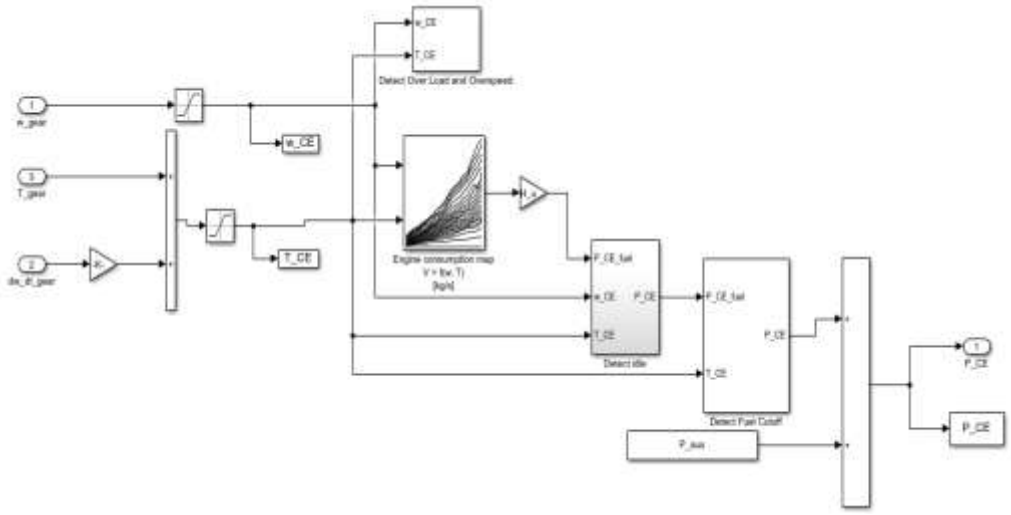

Figure 3. Combustion engine Model

At higher demands, flywheel needed to run at high velocity then intake of fuel becomes increase to fulfill the demand of vehicle. Sometimes combustion engine is responsible to give power to vehicle and at the same time it gives power to batteries but due to very good participation of batteries and engine, hybrid control system play important role in fuel consumption criteria.

2.4 Drive Cycles

Drive cycles are required to test Hybrid Electric Vehicle model. A driving cycle is therefore a fixed schedule of vehicle operation by which an emission test could be conducted under controlled conditions. Drive cycles normally described on the basis of vehicle speed [11] and gear selection of vehicle as a function of time. Following is the NEDC drive cycle.

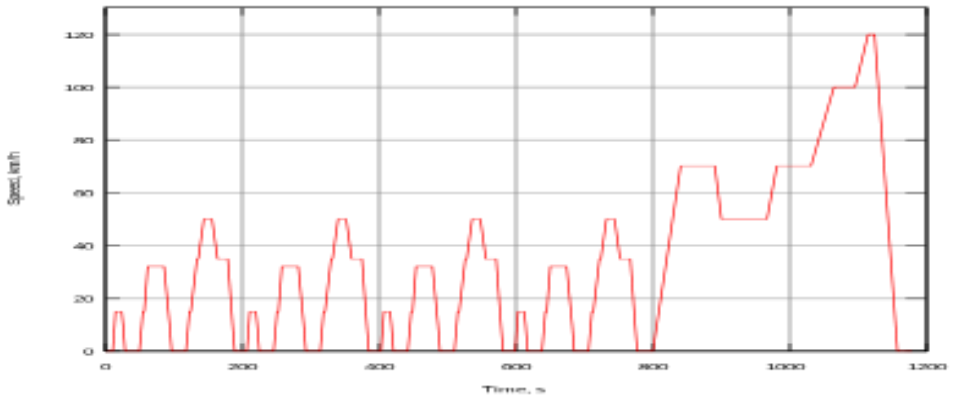

Figure 4. NEDC drive cycle

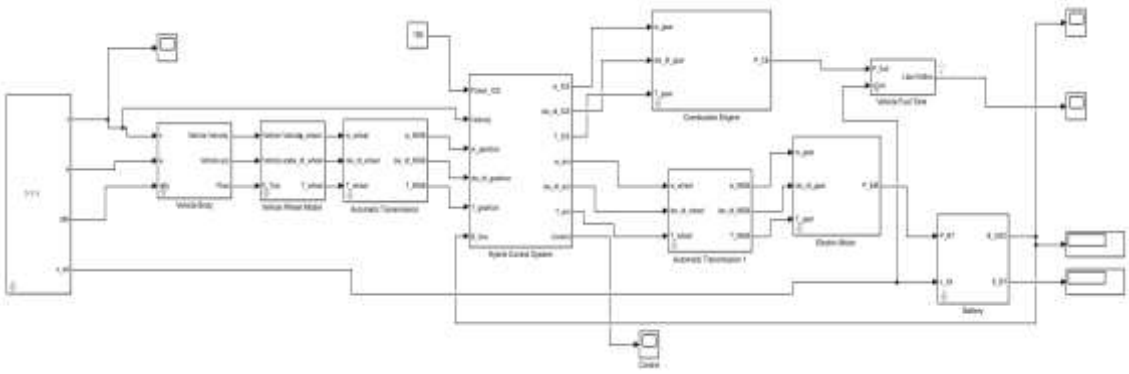

Figure 5. Parallel hybrid electri vehicle matlab model

3. COMPARING AND ANALYSIS OF HEV

3.1 6th Gear Automatic Transmission

In automatic gear transmission, number of gears can be increased according to our requirement to decrease fuel consumption. In this case the maximum numbers of gears used are 6. Following is the gear ratios of 6th gear transmission.
[4.32 2.46 1.66 1.23 1.00 0.85]

As previous situations, here the ratio is decreasing as well with the same pattern. The difference of gear ratios at start is bigger and slightly it lower down to 0.85 for 6th gear. It is the most appropriate gear ratio for this model because vehicle has more steps to shift the gears and this thing gives best impression on fuel economy.
Switching points of upshift of gears are given below in km/h.
[8 18 33 48 70]

Switching points of 6th gear transmission is quite closer as compared to previous transmissions. The difference of gear shifting is very less even less than 11km/h. At start the difference is less and by the increment of gears this difference also increased up to 22 km/h for last gear. By having this switching points engine do not need to work more and electric motor also can take some responsibility where less speed and more torque is required.
In parallel hybrid model not only start stop of car is taken by electric motor but also up to some extent of speed electric motor support to vehicle if the batteries are good charged. At higher power requirements at higher speeds, even in that case electric motor assist to combustion engine until its batteries are having some power in it. This is the most suitable sequence of parallel hybrid to save fuel consumption of gasoline engine because hybrid control system divides power to both sources with much high intelligent way to save fuel of combustion engine.
This distribution of required power among combustion engine and electric motor is already discussed in previous chapter in detail with almost exact feasible values. Two main drive cycles are used to compare and analyze the results of this model on the basis of different gear transmissions.

3.2 Comparing the Analysis Data

The data collected by taking the difference of first two gear ratio and last two gear ratios in each automatic gear transmission is discussed below.

$$0.94 < 1.62 < 1.86 \quad (7)$$

$$0.33 > 0.19 > 0.15 \quad (8)$$

From "Eq.(7)" it can be seen that the ratios from 4th to 6th gear is increasing because in gear up smaller gear is driven by larger gear which creates a faster RPM at the output but less torque. So by coming from 4th gear to 6th gear transmission it is increasing because more different steps for shifting power are involved and by appropriate distribution of power by hybrid control system the required power distributed among electric motor and combustion engine which improves fuel economy of vehicle with 6 gear automatic transmission.

From "Eq.(8)" it can be seen that ratios from 4th to 6th gear is decreasing because due to the involvement of more gears the difference between last gear ratios is very less by the increasing number of gears.

3.3 Graphical Representation of Analysis Results

3.3.1 EUDC drive cycle representation

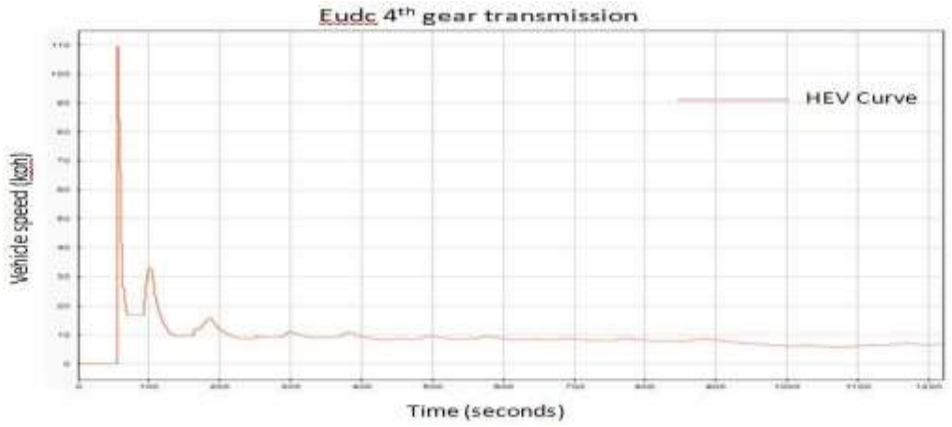

Figure 6. EUDC drive cycle 4 gear automatic transmission

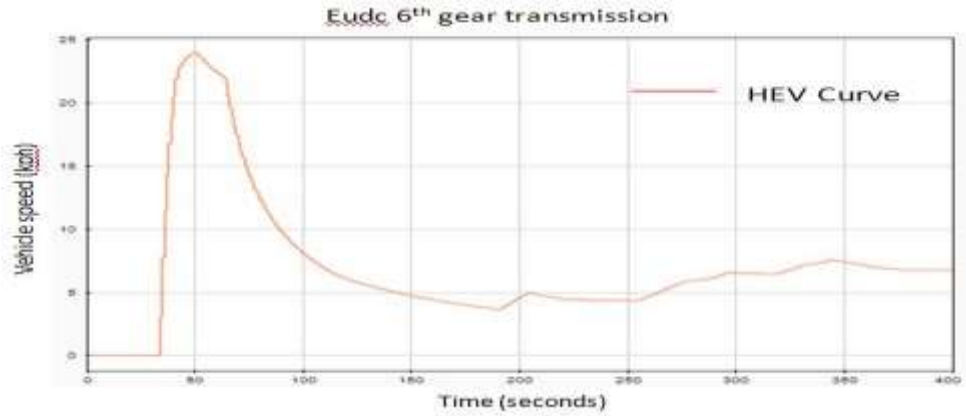

Figure 7. EUDC drive cycle of 6th gear transmission

From the graph it can be seen that by increasing number of gears from 4th to 6th the drive of vehicle becomes smooth and its fuel consumption is very good. In case of EUDC, its fuel consumption was 7.223L/100km for four gear transmission but with 6 gear transmission it was 6.782L/100km.

3.3.2 NEDC drive cycle representation

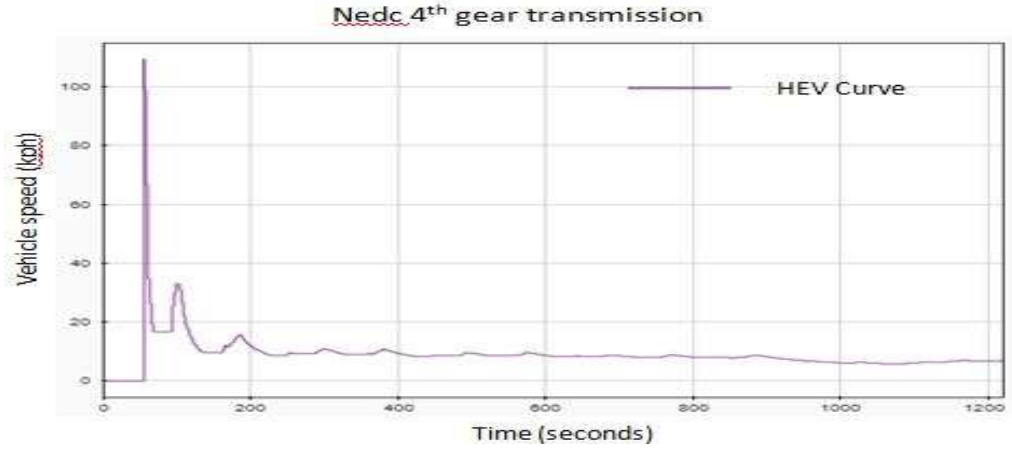

Figure 8. NEDC 4th gear transmission

Figure 9. NEDC 6th gear transmission

In case of NEDC, initially for 4th gear automatic transmission it was showing 6.575L/100km but in case of 6ht gear transmission it was showing 5.767L/100km. So it is obvious from these values that by increasing number of gears the cost gets high little bit but most importantly these vehicles save fuel and alternately they are saving thousands kg of CO_2 from environments to pollute it.

3.3.3 FTP_75 Drive cycle representation

Federal test procedure is designed to deeply measure the emissions and fuel economy of light duty vehicle. As originally this drive cycle designed for fossil fuelled vehicle so its distance is kept more about 17.77km with average speed of 34.1 km/h in 1874 seconds.

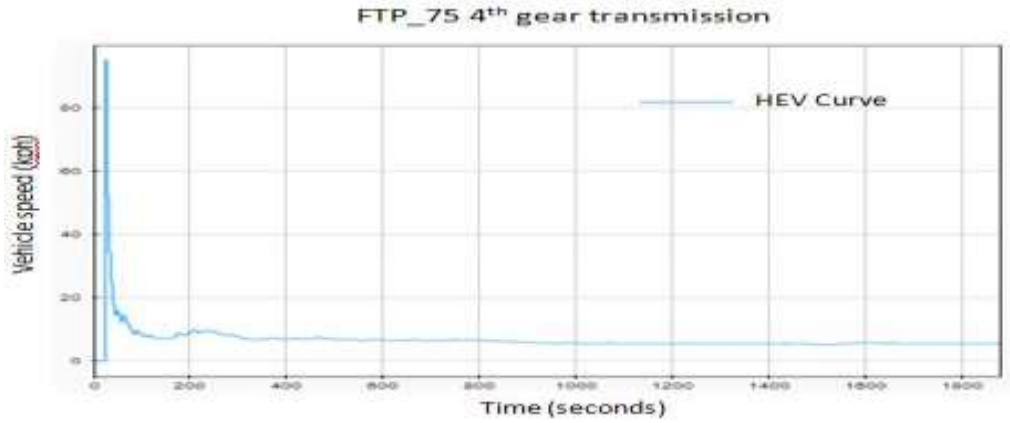

Figure 10. FTP_75 drive cycle 4th gear automatic transmission

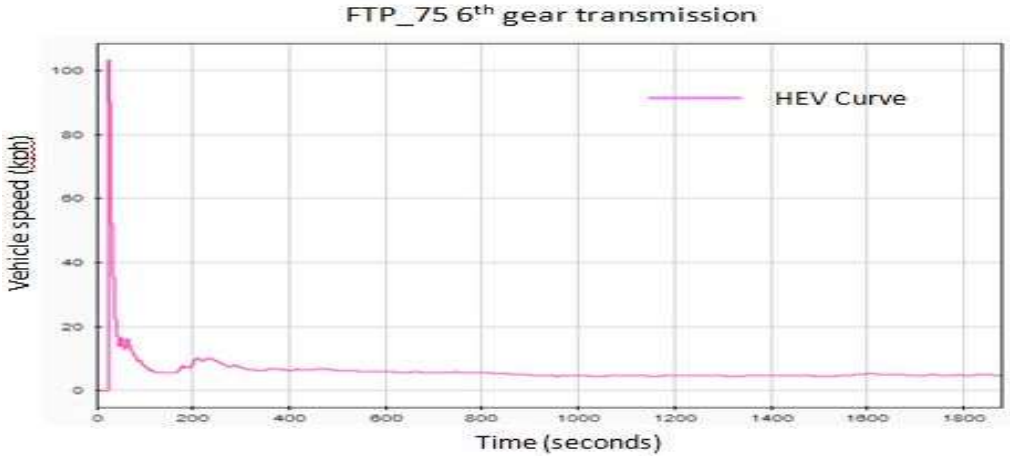

Figure 11. FTP_75 drive cycle for 6th gear transmission

Above drive cycles is FTP_75. From this comparison, It can be seen that the results of these graphs are most effective and having better fuel consumption. In case of 4th gear automatic transmission, vehicle could travel 5.429L/100km. For 5th and 6th automatic gear transmissions the gear ratio is quite changed to get most beneficial results, so in case of 5th gear this consumption is more efficient with 5.099L/100km. The best ever fuel consumption is taken by 6th gear automatic transmission with only 4.83L/100km.

From above graphs it is very clear that by putting more gear and small divisions among gear ratios, fuel consumption of vehicle improved. Now it is proved with figure 4.9 that by having 6th gear automatic transmission vehicle will use only 4.83L for 100km.

4. CONCLUSION

From the results it can be seen that as well as the number of gears were increased , the fuel economy of the vehicle also improved because in this way torque requirement divide in more smaller steps and sources need to do less work to fulfil their requirements which helped in improving fuel consumption.

A lot of part are here for future work, design of the automobile is very important because not only the upper shape but also the design of under body, lower side is also very important to focus to improve and decrease air resistance. More over by changing battery type weight of the car could be discussed and figured out as it directly affects the power of the vehicle. A very important factor could be sorted out for future work is the optimization of the hybrid control system.

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.5. REFERENCES

[1] DeMeritt, Jacqueline H. R., and Joseph K. Young. "A Political Economy of Human Rights: Oil, Natural Gas, and State Incentives to Repress1." *Conflict Management and Peace Science*, vol. 30, no. 2, pp. 99–120, Apr. 2013.

[2] Toyota prius review 2010, [online]. Available: https://www.thecarconnection.com/overview/toyota_prius_2010

[3] Soroush Shafiee, Mahmud Fotuhi-Firuzabad, Mohammad Rastegar. " *Investigating the impacts of Plug-In hybrid electric vehicles on power distribution systems,*" IEEE transactions on smart grid, Vol. 4, No. 3, September 2013.

[4] L. Jinming, "*Modelling, Configuration and Control Optimization of Power Split Hybrid Vehicles*", PhD Thesis, University of Michigan, 2007.

[5] Hybrid electric-petroleum vehicles. https://en.wikipedia.org/wiki/Hybrid_vehicle#Hybrid_electric-petroleum_vehicles.

[6] K. L. Butler, M. Ehsani and P. Kamath, "A Matlab-based modeling and simulation package for electric and hybrid electric vehicle design," in *IEEE Transactions on Vehicular Technology*, vol. 48, no. 6, pp. 1770-1778, Nov. 1999.

[7] Wolfram Buschhaus, Bradford Bates, Richard C. Belaire, Allan R. Gale, *Parallel Hybrid Powertrain for an Automotive Vehicle,* US5713425A, 1996.

[8] G. Paganelli, S. Delprat, T.M. Guerra, J. Rimaux, J.J. Santin, *Equivalent Consumption Minimization Strategy for Parallel Hybrid Powertrains, Columbus,OH, USA 2018.*

[9] X. Zeng and J. Wang, "A Parallel Hybrid Electric Vehicle Energy Management Strategy Using Stochastic Model Predictive Control With Road Grade Preview," in *IEEE Transactions on Control Systems Technology*, vol. 23, no. 6, pp. 2416-2423, Nov. 2015.

[10] S. M. Lukic and A. Emadi, "Effects of drivetrain hybridization on fuel economy and dynamic performance of parallel hybrid electric vehicles," in *IEEE Transactions on Vehicular Technology*, vol. 53, no. 2, pp. 385-389, March 2004.

[11] Achour, Hussam & Olabi, Abdul Ghani. "Driving Cycle Developments And Their Impacts On Energy Consumption Of Transportation." *Journal of Cleaner Production*. Aug. 2015.

[12] M. Aboulkheir, "Development of Dual Clutch Transmission model for Hybrid Vehicle", *Int. J. Innov. Technol. Interdisc. Sci.*, vol. 1, no. 1, pp. 26-33, Nov. 2018.

[13] J. Pumwa, "Time Variant Predictive Control of Autonomous Vehicles", *Int. J. Innov. Technol. Interdisc. Sci.*, vol. 1, no. 1, pp. 62-77, Nov. 2018.

[14] S. Parman, "Fuzzy Logic Control of Clutch for Hybrid Vehicle", *Int. J. Innov. Technol. Interdisc. Sci.*, vol. 1, no. 1, pp. 78-86, Nov. 2018.

[15] T. Poulain, "Trajectory Generation and Control of Autonomous Vehicles", *Int. J. Innov. Technol. Interdisc. Sci.*, vol. 2, no. 1, pp. 200-211, Jan. 2019.