COMPUTATIONAL ASSESSMENT OF SPEED CONTROL STRATEGY DURING MODE CHANGE OF PARALLEL HYBRID ELECTRIC VEHICLE

[1]Deep A Patel, [2]Jitendra K Chauhan
[1]M.Tech., [2]Assistant Professor
Department of Automobile,
Parul institute of engineering and technology,Parul University, Vadodara, India.

Abstract: This study has been undertaken to investigate drivability of Hybrid Electric Vehicles, when parallel hybrid powertrain structure performs mode changing torque delivery of the power source also changes from electric motor to engine or vice versa whose effect can be seen on ride comfort. To improve mode changing process parallel hybrid electric vehicle is developed using MATLAB/Simulink Tool. The jerk of vehicle is used to evaluate vehicle's drivability. A controlled torque is applied during mode changing after studying the cause of jerk. Analysis results shows that optimized torque control of engine and electric motor during mode changing process gives reduction in the jerk of vehicle.

***Index Terms* - MATLAB/Simulink, Hybrid vehicle, Mode change, Torque control, Vehicle jerk analysis.**

I. INTRODUCTION

The parallel HEV can transmit power individually from electric motor and from engine like conventional vehicles to the transmission unlike series HEV structure where engine is only used to generate electric power through the generator and motor only is connected to transmission so mode changing of parallel HEV is important aspect which describes vehicle drivability.

Drivability of vehicle describes vehicle longitudinal dynamic behavior. Jerk is chosen to describe vehicle drivability as it can be easily synchronized with human feelings during bumpy and bad road conditions and mode changing process [Refs 1]. past researches conducted to describe how jerk relates with drivability done by Quanan Huang and Huiyi Wang studied that max value of jerk should be lower than 10 m/s^3, so influence of jerk exerted on human is almost same and hard to distinguish [Refs 3].

Due to change of powertrain system jerk produced in HEV is more than IC engine vehicle as it changes power source because both motor and engine has different torque-speed behavior. In previous studies researches are done to reduce shocks, vibrations and duration of mode change[Refs 2]. This paper focuses on the control strategy to enhance vehicle drivability by reducing torque difference between electric motor and engine during mode changing to provide basis for enhancement of vehicle drivability.

II. VEHICLE CONFIGURATION AND SYSTEM DYNAMICS

Vehicle structure has parallel hybrid powertrain which is selected as a platform to study and analyze the overall drivability. Figure 1 shows hybrid configuration which consists an Engine, Electric motor, clutch, transmission and battery. Engine clutch allows the engine or the motor to propel the vehicle alone. In addition integrated Starter Generator helps engine to start, to increase engine torque and to charge the battery when required. Important powertrain parameter are shown in Table 1. parallel HEV model developed using MATLAB/Simulink based on system dynamics and some previous researches with experimental data.

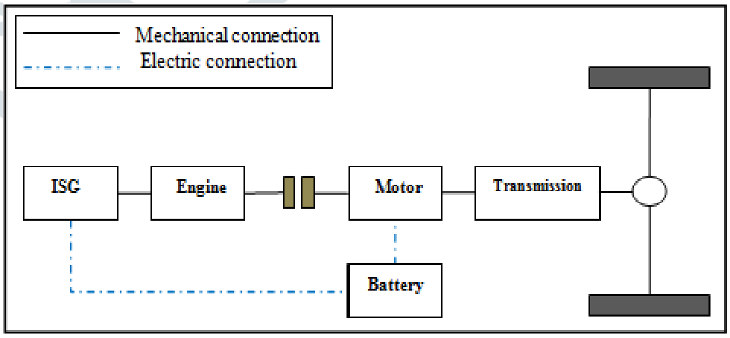

Figure 1. Vehicle Configuration

2.1. Engine Model: Spark ignited internal combustion engine having 51kW of power generating capacity at speed of 5000 rpm and redlines at 6000 rpm is selected for the model with the help of calculations of maximum power generated by engine and required maximum torque by engine to propel the vehicle.

Table 1. Powertrain Specifications

Components	Parameters
IC engine	1.6L, 51kW/5000rpm, 142Nm/4500
Electric Motor	Maximum power: 30kW No Load speed: 15000rpm
ISG	Maximum power: 3kW No Load speed: 5500rpm
Li-ion Battery	Capacity: 25Ah Power density: 800W/kg
Transmission	Type: AMT Forward: 3.42/1.81/1.28/0.98 Reverse: 3.5
Final Drive	Ratio: 4
Vehicle dynamics	Vehicle mass: 1400kg Frontal area: 3m² Drag coefficient: 0.33 Rolling resistance coefficient: 0.014

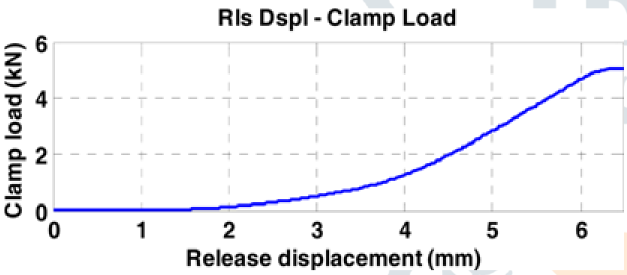

Figure 2. Characteristic curve of Clamp load and Release displacement of the clutch

Table 2. Main clutch parameters

Parameters	Dry clutch
Clutch outer diameter	0.215 m
Clutch inner diameters	0.150 m
Friction coefficient	0.3

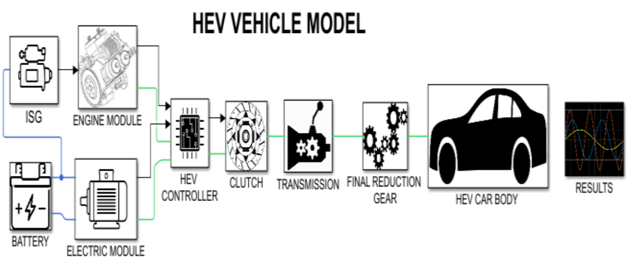

Figure 3. PHEV Performance Simulator

2.2. Electric Motor Model

2.2.1. Main propulsive motor

PMDC motor having maximum power of 30kw and No-Load speed of 15000 rpm is selected by calculating max torque required to propel the vehicle alone by Motor has 162.91 N.m.

2.2.2. ISG

ISG provides required power to the engine for cranking and also it can be utilized as generator from the engine which is connected to the engine with the help of belt pulley. also can be used to synchronize engine torque.

2.3. Engine clutch Model

Input to the engine clutch is connected to the power output shaft of the engine and output shaft is connected with the motor which transmits power to the driveline. clutch can connect and disconnect the engine output power with the driveline. Now clutch bearing displacement to change position of clutch pressure plate and required clamp load at the actuator can be determined by clutch characteristics experiment which is taken as reference from the past research study as shown in figure 2.

2.4. Transmission Model

In this study vehicle transmission chosen is Automated Manual Transmission which is most affordable in the range of automatic transmission lineup. Gear ratios are fixed which helps to identify jerks easily.

2.5. Longitudinal Vehicle Model

It represents a vehicle body in longitudinal motion and describes body mass, aerodynamic drag, road incline & weight distribution between axles due to acceleration and road profile. Vehicle tractive force can be calculated here as F_t-F_i-F_f-F_w=δma. where m is vehicle mass, a is acceleration, F_i, F_f and F_w are grade resistance, rolling resistance and aerodynamic drag respectively.

2.6. Battery Model

Voltage of battery can be calculated as V_b=OCV- $i.R_b$, where OCV is (Opan circuit voltage) and R_b is internal resistance, current can be calculated as sum of main electric motor and ISG which is $i = i_m + i_{ISG}$. if sign of current is positive than motors are generating power to propel vehicle and if negative motor works as a generator to charge battery. $i_m = \frac{Pm(ISG)}{Vb}$.

PHEV performance simulator as shown in Figure 3 is developed using MATLAB/Simulink Tool which is used to Analyze vehicle drivability in terms of Jerk developed during mode change and also gives jerks developed because of engine and motors own behavior

III. SYSTEM MODELING

Calculations to get the value of power and torque required to propel the vehicle are shown here,

Wheel radius = R_w,, linear distance traveled = $2\pi R_w$,

$$\text{RPM} = \frac{\text{Total distance covered/ hour}}{\text{linear distance}},$$

Power =[(M in kg)*(Acceleration .g in m/s²)*(Velocity in m/s)*(R_r)] + [(air density)*(drag coefficient C_d)*(Area m²)*(V^3)]....(3.1)

Power output = Efficiency * Power input which means τ*ω = η*Power and angular velocity can be expressed as $\omega = \frac{2\pi * RPM}{60}$

Torque required to propel the vehicle can be calculated from above equation.

DRIVABILITY EVALUATION (JERK)

Drivability can be evaluated in terms of Jerk produced by vehicle & jerk is change in the rate of acceleration with respect to time. $j = \frac{da}{dt}$, where a is vehicle acceleration. According to Newton's second law of motion we know that F_t-F_i-F_f-F_w=δma. where F_t, F_i, F_f and F_w are drive/brake force, grade resistance, rolling resistance and aerodynamic drag respectively and m is vehicle mass, a is vehicle acceleration.

Because of hybrid powertrain consideration F_t cab be evaluated from T_m and T_c which are motor and clutch torque respectively. $F_t = \frac{io*ig}{r}(Tc + Tm)$, where $i_o.i_g$ is final gear ratio and r is effective tire radius. it is assumed here that F_i, F_f and F_w have very little contribution in relation with jerk. Degree of jerk can be expressed as $j = \frac{io*ig}{\delta mr}\frac{d(Tc+Tm)}{dt}$ ....(3.2)

Now T_c is 0 when clutch is OFF, but it can be found out as follow when clutch is engaged. $T_c = \frac{2}{3} Z\mu W(r_2^3 - r_1^3/r_2^2 - r_1^2)$....(3.3)

where Z is number of friction plate, μ is friction coefficient, W is clamp load, r_2 is outer radius and r_1 is inner radius.

IV. ANALYSIS OF RESULTS

4.1. STARTING AND ACCELERATION IN MOTOR ONLY MODE:

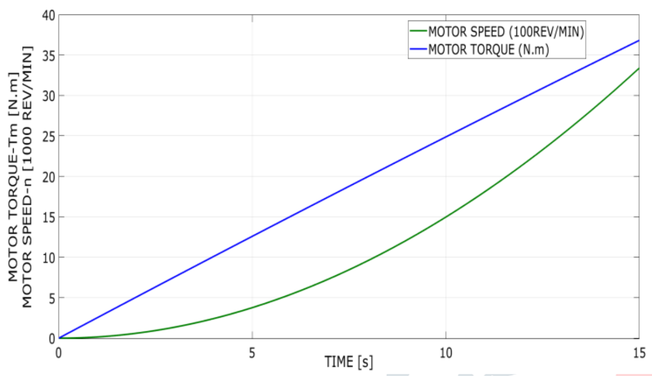

Figure 4. Motor Torque-Speed Curve

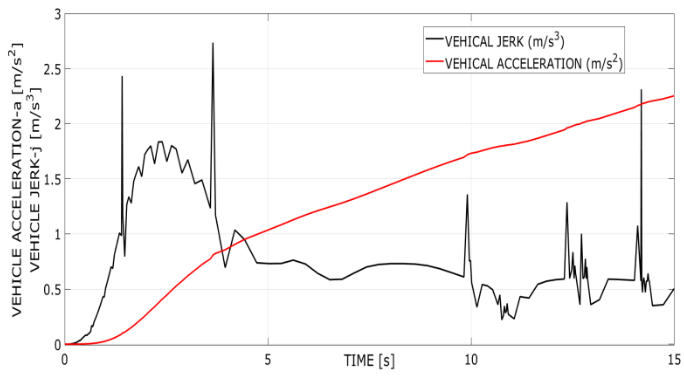

Figure 5. Vehicle Acceleration & Jerk by Motor

First vehicle starts with the throttle input linearly increase with time so torque and speed both increases gradually with time and because vehicle is accelerating in Motor only mode, the degree of the jerk depends on the Motor output behavior.

4.2. STARTING AND ACCELERATION IN ENGINE ONLY MODE:

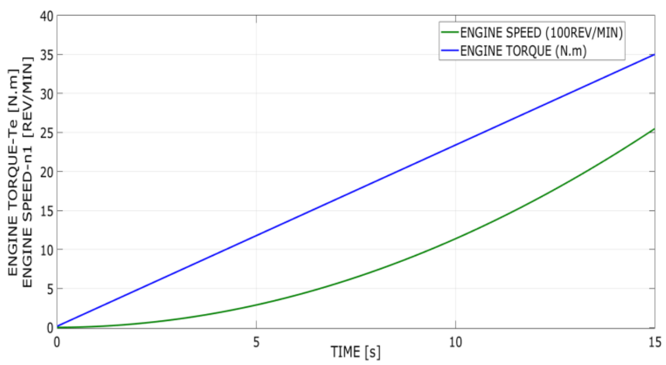

Figure 6. Engine Torque-Speed Curve

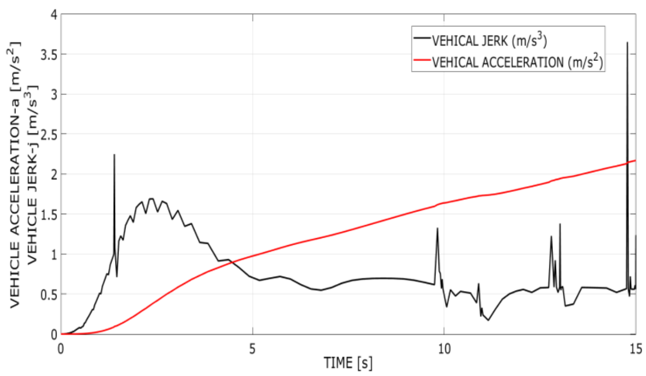

Figure 7. Vehicle Acceleration & Jerk by Engine

Vehicle starts and Engine throttle input increases linearly with respect to time and engine behavior is tuned to get linear torque delivery with gradual increase in throttle to get mature acceleration behavior of Engine which is responsible to give vehicle jerk result

4.3. MOTOR ONLY MODE TO ENGINE ONLY MODE:

Jerk becomes more intensive when speed difference between rotation speed of motor and engine are more than preset rotation speed. when changing from motor only to engine only mode ISG helps engine to revolve at speed nearer to motor for smooth mode change process where clutch is playing important role because of torque transfer behavior of clutch to the rest of the driveline. Mode changing condition ensure that when speed of motor and engine are within preset condition only then it switches the mode so jerk will be within the controlled magnitude where it's influence is hard to distinguish.

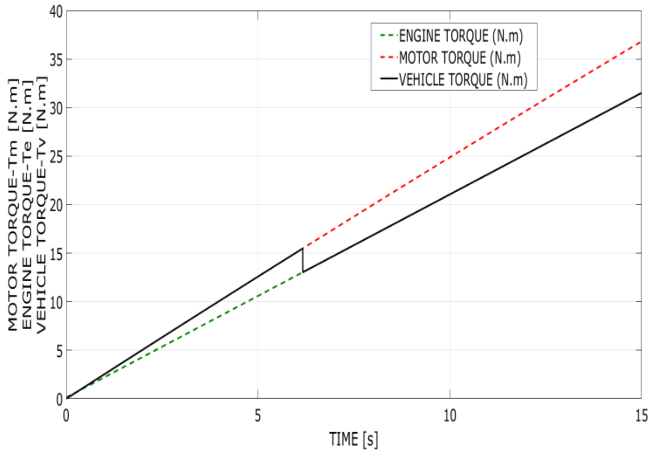

Figure 8. Mode change without control logic applied

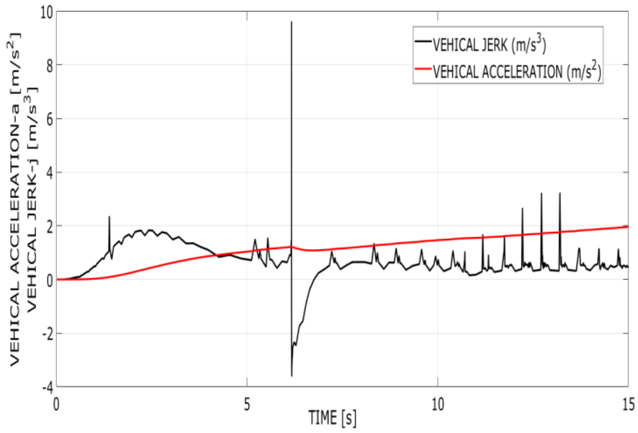

Figure 9. Acceleration & Jerk during mode change without control logic

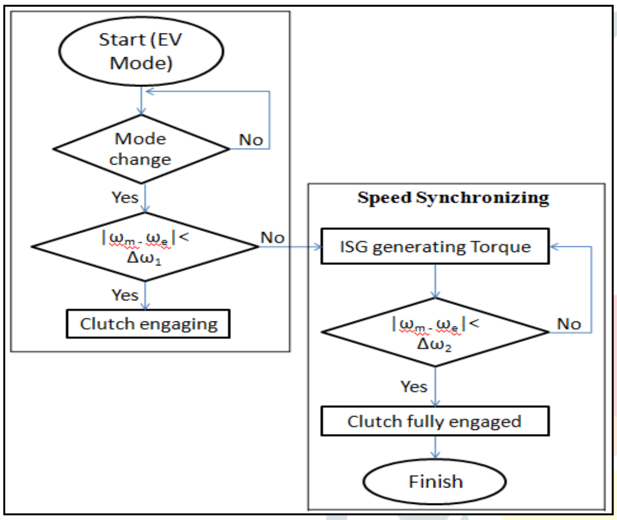

Figure 10. Flow chart of the mode change for the EV to HEV transition with the engine compensation torque.

As shown in result of SIMULINK model during mode changing from motor only to engine only because of adequate torque difference intense jerk is developed so torque synchronization is necessary. Figure 10 shows a flow chart of the electric vehicle to hybrid electric vehicle mode change transition at the powertrain with the engine compensated torque. when mode change is actuated difference between angular speed of motor and engine are compared. A proportional plus integral (PI) controller is used for this comparison and to reduce the speed difference. The integrated starter generator is used to generate a torque which increases the engine shaft speed. The time duration during the mode changing when the engine torque increases is elapsed time. If ISG fails to synchronize this speed difference quickly than mode change duration also increases. The problem can be solved by ensuring that ISG generation torque is more than the idling speed of the engine and proportional plus integral controller helps to synchronize speed rapidly.

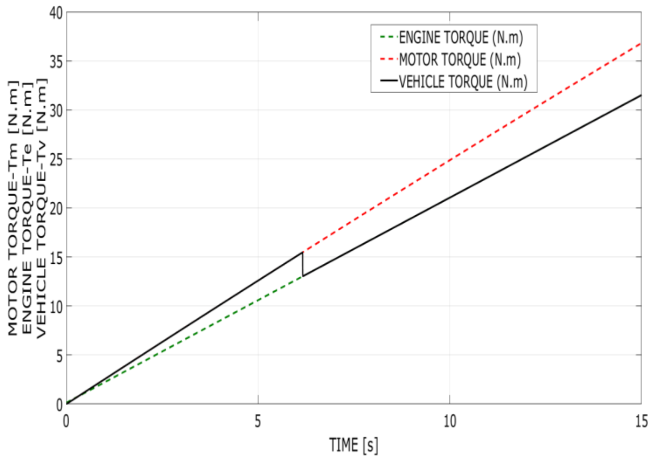

Figure 11. Mode change with control logic applied

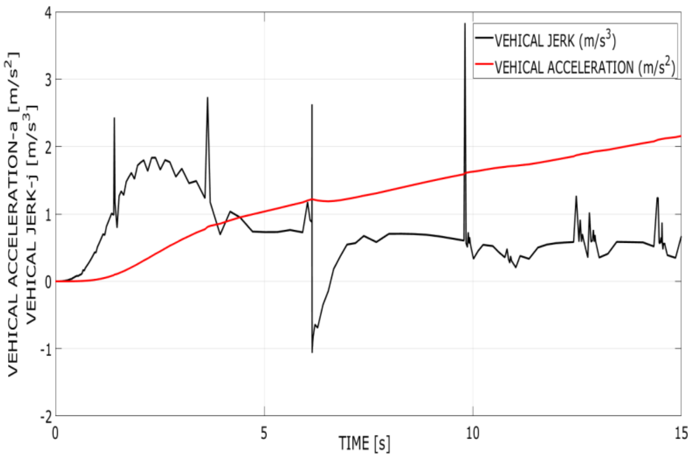

Figure 12. Acceleration & Jerk during mode change with control logic

As shown in result of SIMULINK model during mode changing from motor only to engine only after torque synchronization technique applied drop in torque when clutch is engaging is reduced and so that frequent drop in vehicle acceleration also reduced and so reduction in vehicle jerk is noticed when compared to Mode changing process done without torque synchronization logic applied.

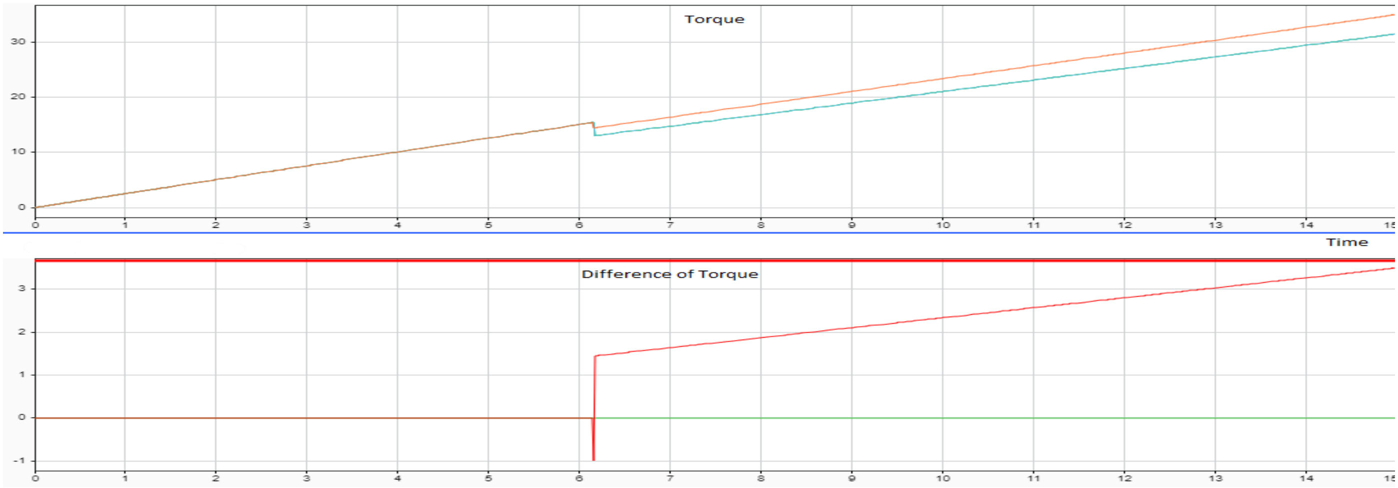

Figure 12. Comparison of Torque before & after control logic applied

Comparison of torque difference during mode change because of clutch engagement process there is drop in torque for an instant when torque demanded by powertrain shifts from electric motor to engine which is shown in above figure.

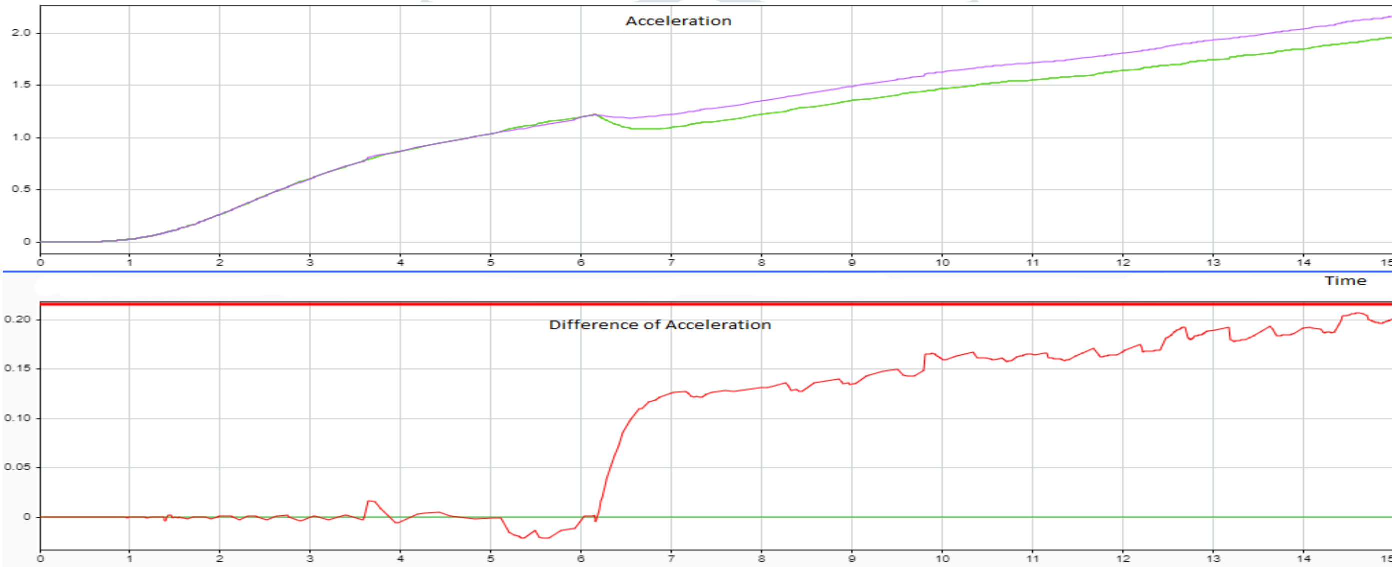

Figure 12. Comparison of Acceleration before & after control logic applied

At the time of clutch engagement when mode change actuates there is instant drop in torque delivered to powertrain and because of that there is drop in acceleration. Comparison of the acceleration drop difference is shown above to understand effect of torque and speed synchronization control logic implemented to reduce difference.

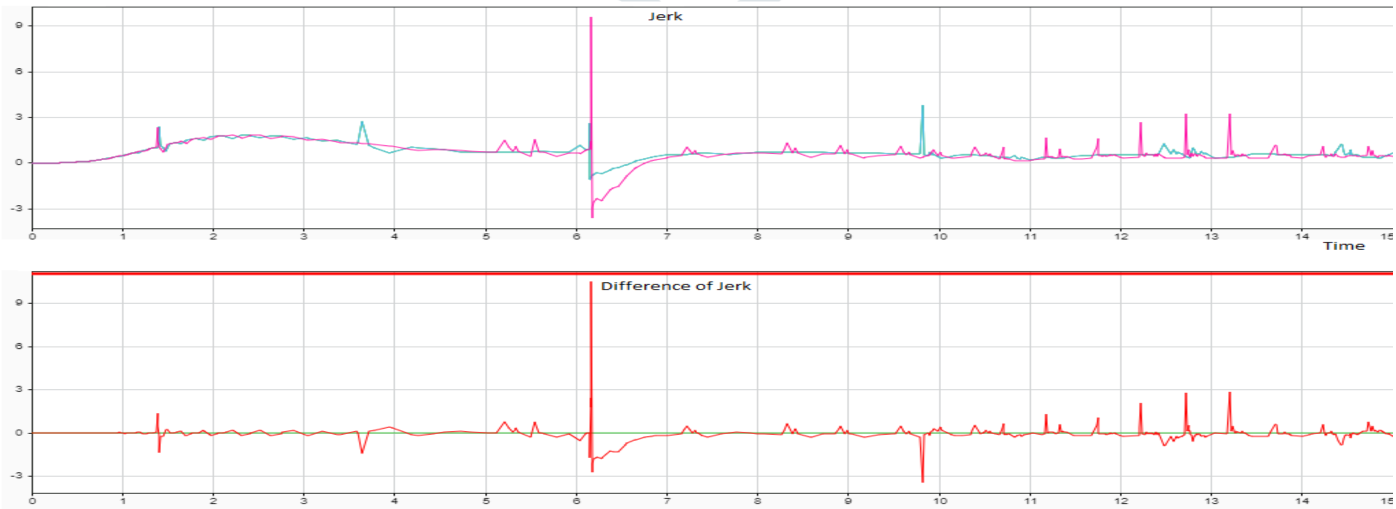

Figure 13. Comparison of Jerk before & after control logic applied

Jerk reduction at the time of mode change after torque synchronization logic applied to actuate proper clutch engagement process can be seen clearly which is result of reduction in torque drop during mode changing process and by comparing jerk developed before and after control logic applied result shows 10.54 m/s^3 of reduction in developed jerk.

V. CONCLUSION

This study includes control strategy of engine speed and torque control to enhance mode change process of parallel hybrid electric vehicle. To achieve drivability engine, ISG and clutch plays very important role in this study. When starting in motor only mode there can be a high degree of jerk due to motor torque delivery behavior, during mode changing process jerk could become intense due to speed and torque difference between engine and motor. It can be concluded from this study that by reducing speed and torque difference during mode changing improves drivability by reducing degree of Jerk in parallel HEV.

I. ACKNOWLEDGEMENT

The submission of the report gives me opportunity to thank all those who have helped me in completion of project work. I hereby would like to Acknowledge the invaluable support of my project guide Prof. Jitendra K Chauhan, Department of Mechanical Engineering, PIET, Vadodara. He helped me through his invaluable suggestion and support throughout the subject of the Research Methodology and has been an unending source of inspiration for me. I am also thanked other faculty members who have directly or indirectly helped me whenever it was required by me. I owe my special thanks to, my friends for supporting and encouraging me in all possible ways and also all faculty members of Mechanical Engineering Department for the knowledge they imparted me throughout the Project.

REFERENCES

[1] A Study on the Drivability of Hybrid Electric Vehicle, Junzhi Zhang and Xin LU Lifang Wang, Shanglou Chen and Shoubo LI.

[2] Control Strategy for Clutch Engagement during Mode Change of Plug-In Hybrid Electric Vehicle, Kyuhyun Sim, Sang-Min Oh, Choul Namkoong, Ji-Suk Lee, Kwan-Soo Han and Sung-Ho Hwang.

[3] Fundamental Study of Jerk: Evaluation of Shift Quality and Ride Comfort, Quanan Huang and Huiyi Wang.

[4] Powertrain Design and Experiment Research of a Parallel Hybrid Electric Vehicle, C.-L. Wang, C.-L. Yin, T. Zhang And L. Zhu

[5] Development of Engine Clutch Control for Parallel Hybrid Vehicles, Joonyoung Park.

[6] Control Strategy Development for Belt-Driven ISG(Integrated starter generator) System applied to the Parallel Hybrid Vehicle Huyong Jung, Hyungsuk Lee, Junseoung Rhee, Seungho Lee.