International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-5, March 2019

Modelling and Analysis of Split Parallel Hybrid Electric Vehicle based on 14 Degrees of Freedom

C. Parag Jose, Haneesh K.M

Abstract: ***The paper studies the scope, performs the modelling and validation for conversion of any Convetional Vehicle to a Split Parallel Hybrid Electric Vehicle. The introduction of a smart Energy Management System for sucha setup is also evaluated. The EMS enables load sharing between the IC Engine and the Traction motor based on the gradient of the road. The gradient analysis is performed using the GPS based road gradient database. For the accurate modelling and the dynamic analysis of the designed model the performance of the vehicle's Degrees of Freedom (DoF) for the variation in steering angle is analyzed. 14 DoF parameters are considered and the designed vehicle is subjected to variation in steer angle followed by the analysis on the response of the DoF parameters.***

Keywords: ***DoF, Reva-I, HEV, ICE, SoC.***

I. INTRODUCTION

The importance of alternative fuels or energy sources, and relevance of improved powertrain technologies is on the rise for past few years. This is mainly due to the depletion of fossil fuel sources and due to the rocketing fuel prices. The alarming rate of global atmospheric pollution is the main cause of phenomenons like global warming, acid rain and features like smog. These conditions are attributed to the sudden hike in lung diseases and cancer related cases around the world. India, being second largest populated country, has cities with the greatest human density when compared all over the world. The common source of transportation being IC engine based vehicles. These have been the popular form, due to the affordable initial and maintenance costs as compared to other Electric Vehicle counterparts. This, along with negligible Electric Vehicle charging infrastructure available, has made the Electric Vehicle technology being shunned by the Indian population. Even though the Government of India and some states like Government of Karnataka, are trying to promote the utilization of Electric Vehicle technologies through policies like National Electric Mobility Mission Plan 2020 (NEMMP) [1] and Karnataka Electric Vehicle & Energy Storage Policy 2017 [2], the mobilization of Electric Vehicles are still in its infancy. Therefore the scope and market for hybridization of the conventional IC Engine vehicles is very high. By the hybridization process, there is a drastic reduction in the Energy consumption in terms of reduction of fossil fuel usage. It also enables to reduce the Well –to –Wheel (WTW) Greenhouse Gas (GHG) Emissions.[3] With the upcoming BS-V and BS-VI standards, this would also help in regulating the critical emissions thereby reducing factors causing Global Warming and other environmental issues. As the process of hybridization involves minimal modifications, it helps to maintain consumer acceptability in terms of performance, maintenance and also safety making the utilization of such vehicle more economical. As the concepts of connected cars and improved powertrains are becoming a prominent part in the automotive industry, the need for more advanced and exhaustive methods of powertrain design and analysis has become a necessity. The facility to create and validate realistic vehicle models through simulation software like Advisor, has created an opportunity to test hybrid powertrain layouts in a simulation setting. This plays a very important role in component sizing which enables to meet the desired vehicle specifications. Using the Advisor software varying component sizes and different and more efficient and feasible powertrain configurations can be tested and the result analysed and validated. Advisor based modelling enables preliminary comparisons that could be made between powertrain configurations, and also specific comparisons in terms of the vehicle performance, energy consumption and exhaust produced. The concept of Split-Parallel Hybrid Electric Vehicle has been researched and well documented [4],[5]. The process of Torque coupling for such a configuration is considered to be one of the innovative approaches in power train design. This approach is known as the through the road (TtR) approach [4],[5]. The vehicle fuel consumption has been used as an indicator to evaluate the performance of a TtR model and was found to reduce the fuel consumption by around 32% as compared to the IC engine model[6]. The modelled vehicle should be subjected to Dynamic Analysis to verify and validate the efficiency of the designed model in terms of the effect on the Degrees of Freedom. The response to parameters like yaw, Pitch and slip are to be validated. The modelling for a comprehensive analysis of the 14 DoF of a vehicle model considering the impact of change in vehicle geometry on the dynamic of roll centre and nonlinear effect was performed [7]. To evaluate the phenomenon of slip with due consideration of camber was performed by developing the tyre Pacejka tire model [8]. A detailed study on the effect of parameter changes including step steer and double lane change on the 14 DOF vehicle model was made comparing three tire models available and validation with an instrumented experimental vehicle [9].

This paper presents the Design of a Split Parallel Hybrid Electric Vehicle using Advisor Software by considering Reva-I with a 17hp three phase induction motor as the base model and a Pulsar 220 DTS Fi engine as the IC engine counterpart. The model is simulated to operate using the Worldwide Harmonized Light Vehicles Test Cycle (WLTC) approved Class-I Indian Drive Cycle and the parameters are analysed.

Manuscript published on 30 March 2019.
***Correspondence Author(s)**
C. Parag Jose, Department of Electrical & Electronics Engineering Faculty of Engineering, Christ (Deemed to be University), Bangalore, India
Haneesh K.M, Department of Electrical & Electronics Engineering Faculty of Engineering, Christ (Deemed to be University), Bangalore, India

To evaluate the load sharing between the split power sources a GPS based gradient database is given to the system thereby evaluating the load sharing. The designed model is further subjected to analysis of the 14 DoF to evaluate the performance of the designed model with respect to the variations in the Degrees of Freedom.

II. HYBRID ELECTRIC VEHICLE MODELLING

Hybrid Electric Vehicles are broadly classified as Series Hybrid, Parallel Hybrid and Series- Parallel Hybrid. This classification is based on the configuration of the power train. Unlike conventional configuration the Split Parallel Hybrid power train makes use of two separate power sources driving the rear and front wheels separately. The proposed system as shown in Figure.1 depicts the three phase induction motor driving the front wheels while the IC engine operates the rear wheels.

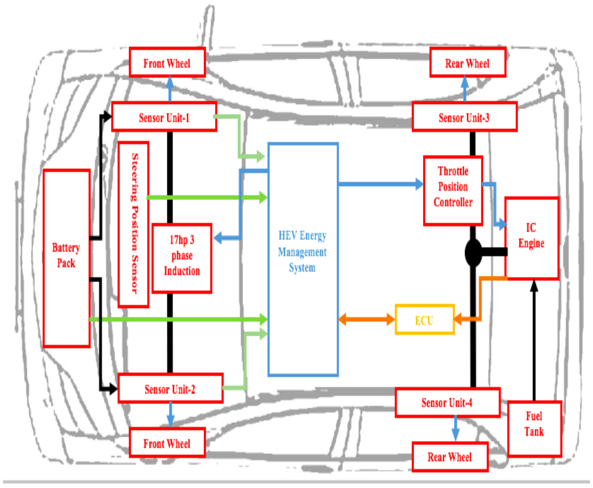

Fig.1: Split- Parallel Hybrid Electric Vehicle model

The Reva-I model makes use of a 17hp three phase induction motor with a boost switch facility to obtain around 40% extra torque for improved acceleration and hill climbing which also enables to improve the top speed to 80kmph. However, the nominal range of the vehicle is only around 80 km. The proposed method could be used to change any conventional IC Engine vehicle to a Hybrid Electric Vehicle through minimal modifications. The Steering wheel sensor helps the Energy Management Systems to calculate and control the slip in the four wheels through the motor drive and fuel injection control of both the induction motor and the IC engine. The identified Bajaj Pulsar 220 DTS-Fi engine has a displacement of 220 cc with a maximum power of 19.51 hp. The engine is equipped with an Electronic Fuel Injection system which could be utilized to regulate the engine operation.

Table I shows the considered parameters for the designing of the Hybrid Electric Vehicle using the Advisor software.

Component	Specifications
Dimensions	2638mm X1324mm X1510mm
Kerb Weight	879 kg
IC Engine	19.51hp, 220 cc Bajaj Pulsar 220 DTS-Fi engine
Motor	17hp, 3 phase Induction motor, Reva-I motor
Battery Pack	6.4 V, 3000 mAh Li ion cells (66 No.s)
Transmission	CVT
Torque Coupling	TtR
Drive Cycle	WLTC Class 1, Indian Drive Cycle
Fuel Injection	Electronic Fuel Injection

Table I: Components & Specification Details

The vehicle is subjected to Class 1 Drive Cycle which is specific for Indian roads of WLTC. The HEV model is simulated to operate under the WLTC drive cycle and the parameters including emissions, mileage and energy loss components are analyzed. The kerb weight includes the weight of the vehicle chassis, the motor power train, the IC engine power train and the battery pack. The sizing has been performed using the Advisor software. The energy loss involved is also calculated using the software to determine the areas of concern.

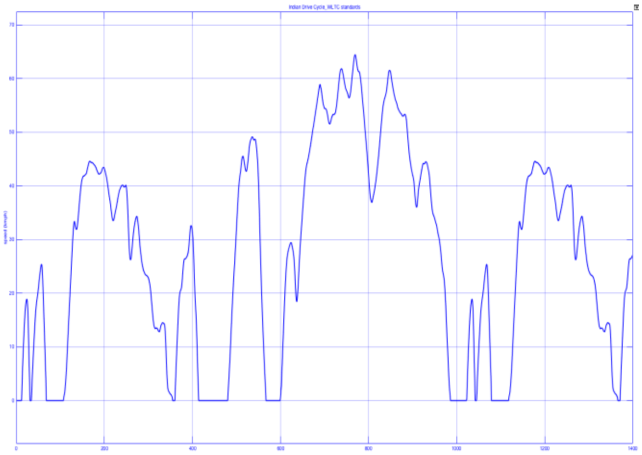

Fig.2: WLTC Class-I Indian Drive Cycle

Figure 2 shows the Class-I Drive cycle as per the WLTC guidelines. The data is being used to test the vehicle for Indian Drive cycle. The Indian Drive cycle comes under Class –I based on the power to mass (PMR) ratio being less than 22 W/kg. The Advisor software has been used to simulate the operation of the proposed Hybrid Electric Vehicle where the Electric Motor, IC Engine and all the other parameters has been designed and input as per Table-I. The rating of the IC Engine has been finalized based on the vehicle dynamic modelling for a rear wheel driven model of the system as given below,

$$F_{t\,max} = \mu W_r = \mu\left[\frac{L_a}{L} Mg\cos\alpha + \frac{h_g}{L}\left(\frac{\mu Mg\cos\alpha\,[L_a\text{-}f_r(h_g\text{-}r_d)]}{L\text{-}\mu h_g} - F_r\left(1\text{-}\frac{r_d}{h_g}\right)\right)\right]$$

where $F_{t\,max}$ is the maximum tractive effort that the tire-ground contact can support, α is the road adhesion coefficient, f_r is the effective radius of the tyre, h_g is the height of the Centre of Mass from the ground, L is the length of the chassis and r_d represents the effective radius of the tyres.

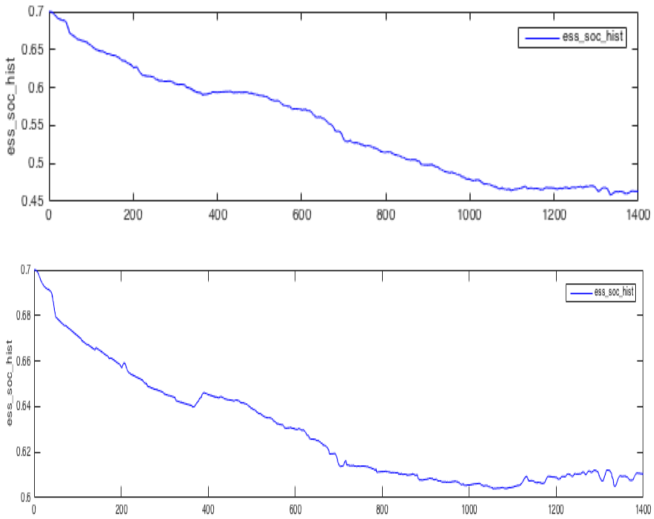

Fig.3: (a) Battery Pack SoC depletion for EV mode (b) Battery Pack SoC depletion for HEV mode

Figure 3(a) shows the Battery Pack SoC depletion level in the based EV model. The EV model was created as per the selected base model parameters and simulated using the Advisor software. The depletion of the SoC during this duration was noted and evaluated. It is seen that for the duration selected for the Indian Driving cycle the battery SoC reduces to around 46% from the intital SoC of 70%. In Figure 3(b) it can be seen that when the HEV model was tested in Advisor the SoC was only reduced to 61% in the same duration for the same Driving cycle. This validates the efficient load sharing between the IC Engine and the Motor based on the terrain and driving conditions.

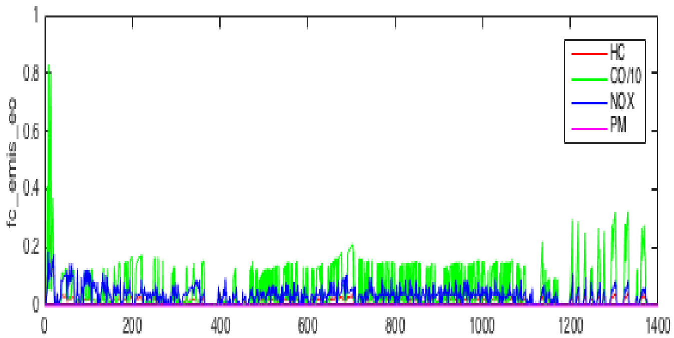

Fig.4: Emission Characteristics

Figure 4 shows the Emission characteristics of the designed HEV. It is found that the level of CO is amounting to 2.80 grams/km, the level of Hydrocarbons is amounting to 0.19 grams/km and the NOx level amounts to 0.10 grams/km. The CO and HC levels are complying with the Bharath Standards-IV (BS-IV) emission standards while the level of NOx emissions are found to be slightly above the permissible emission standards as per BS-IV standards.

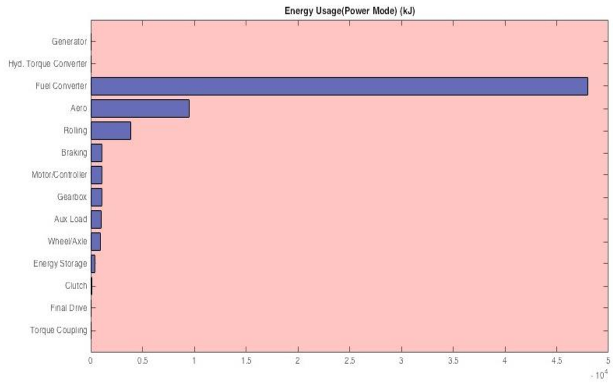

Fig.5 : Energy Usage in the system

Figure 5 shows the Energy utilization data for different components in the power train of the HEV. It is found that based on the driving cycle the majority of the load is shared by the IC engine (denoted as the Fuel Converter) while Motor is used only at certain intervals where more torque is to be provided for the vehicle.

III. Vehicle Dynamic Analysis

The Hybrid Electric model developed in the previous section is further subjected to Dynamic Modelling to verify the effect of the considered parameters on the 14 Degrees of Freedom identified.

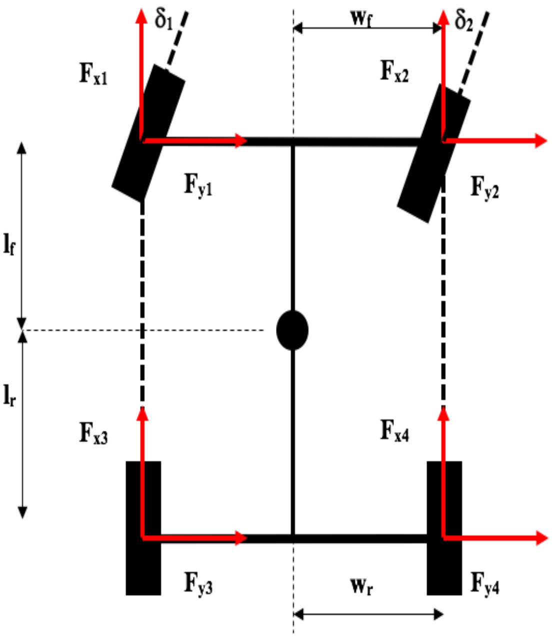

Fig.6: Vehicle Handling Model with the lumped center of mass and roll center

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

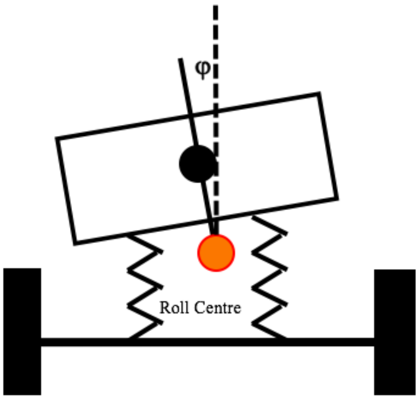

Fig.7: Vehicle Rolling Model with the longitudinal acceleration

The modelled HEV is considered to be a rigid mass with consideration given to the body kerb weight and the unsprung masses. The rigid body is then defined in terms of six degrees of freedom which mainly include *(x,y,z)* the coordinates of the centre of Gravity G_c and the roll, pitch and the yaw angles. Figure 6 shows the mathematical model of the vehicle with the positioning of the lumped rigid mass and the positioning of the Roll centre. The other degrees of freedoms, mainly include, the four vertical deflection forces acting on the wheels, due to the effect of steer angle, on the suspensions of the four wheels and slip angles on the four tyres on the wheels. The tyre modelling has been performed based on the Magic Tyre model done by Pacejka etal. [8]. The base design model, as shown in Figure 6, is called as the *track model* requires several assumptions which includes assuming that the outer and inner steer angles are the same. While performing the modelling it is also necessary to consider the lateral and longitudinal forces induced by the tires are linear also neglecting the effects of any dynamic weight transfer to the wheels. But such a modelling would not provide much manuverability as so the non-linearities involved has to be considered. However, as the vehicle has large number of moving parts it would be difficult to analyse the net effect on each of the parameter and so the model is based on a combination of one sprung mass which is the vehicle body and four unsprung masses which includes the four tyres. The sprung mass is the vehicle mass above the suspension which includes the body, power train, drivetrain and passenger weights while the unsprung mass includes the mass of the components below the suspension which includes the tyres. The higher the sprung mass to unsprung mass, the higher would be the comfort level of passenger travel. But excess values would have negative effect on the vehicle stability as well. The sprung and unsprung masses are further assumed to be a lumped mass. The Degrees of Freedom has been modelled based the *xyz* three coordinate system on the following conditions as defined[7][10] :

The analysis of the vehicle during riding conditions would enable to understand the performance of the developed model with respect to the body acceleration, body displacement, suspension displacement and wheel acceleration.

The body acceleration could be modelled based on the relation:

$$\vec{a}_o=\left(\dot{V}_{ox}-\dot{\psi}V_{oy}\right)\vec{i}+\left(\dot{V}_{oy}+\dot{\psi}V_{ox}\right)\vec{j}$$

where V_{ox} is the chassis velocity along the x- axis, V_{oy} is the chassis velocity along the y- axis and ψ is the yaw angle.

The wheel acceleration could be modelled based on the relation:

$$\vec{a}_{uf}=\left(\dot{V}_{ox}-\dot{\psi}V_{oy}-l_f\dot{\psi}^2\right)\vec{i}+\left(\dot{V}_{oy}+\dot{\psi}V_{ox}+l_f\ddot{\psi}\right)\vec{j}$$

where l_f denotes the longitudinal distance of the front wheels from G_c. Figure 6 and Figure 7 discusses the handling model of the designed vehicle where parameters of pitch yaw and roll could be analyzed. The roll angular acceleration is given by the relation

$$\ddot{\varphi}=\frac{\sum T_{xs}-\left(I_{xzs}-M_sh_sl_{cgs}\right)\cos\varphi\,\ddot{\psi}+\left(I_{xzs}-M_sh_sl_{cgs}\right)\sin\varphi\,\dot{\phi}\,\dot{\psi}+\left(I_{zzs}-I_{yys}-M_sh_s^2\right)\sin\varphi\cos\varphi\,\dot{\psi}^2}{I_{xxs}+M_sh_s^2}$$

where *I* represents the moments of inertia of the sprung mass, M_s represents the mass of the sprung mass h_s represents the vertical distance of G_c from the Roll centre and l_{cgs} represents the longitudinal distance of G_c from the Roll centre.

$$\ddot{\psi}=\frac{\sum T_z-\left(I_{xzs}-M_sh_sl_{cgs}\right)\cos\varphi\,\ddot{\varphi}-\left(I_{xzs}-M_sh_sl_{cgs}\right)\sin\varphi\,\dot{\varphi}^2+\left(I_{zzs}-I_{yys}-M_sh_s^2\right)\sin\varphi\cos\varphi\,\dot{\psi}^2-M_sh_sa_x\sin\varphi-\left(I_{zzs}-I_{yys}-M_sh_s^2\right)\sin\varphi\cos\varphi\,\dot{\phi}\,\dot{\psi}}{I_{zzo}}$$

where T_z represents the total torque about *z* axis. The tyre modelling is based on the Pacejka Magic Tyre model. While modelling the tyre it is necessary to consider the camber angle. Camber angle is the angular distance between wheel vertical axis and vertical axis of the vehicle. When the vehicle wheels operates at this camber angle it develops a lateral force known as the camber thrust, F_y defined as

$$F_y=A\sin\left(B\tan^{-1}\left(Cx-D\left(Cx-\tan^{-1}(Cx)\right)\right)\right)$$

where A =μ F_z

$$C=\frac{C_\alpha}{AB}$$

where C_α is the cornering stiffness of each tire, *x* represents the slip variable, and B, D are the shape factors.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

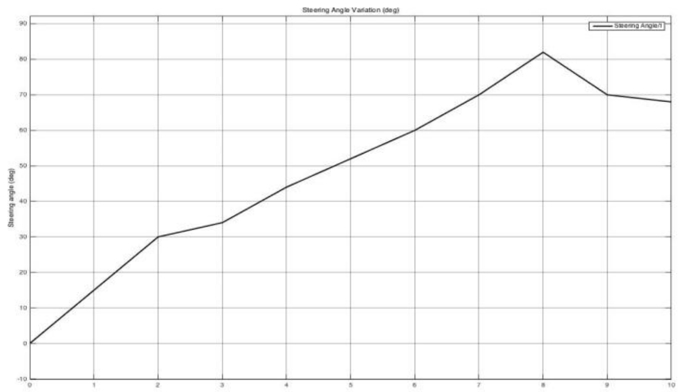

Fig.8: Variation in Steer angle as input for the analysis of the designed HEV model

Based on the modelling performed, the Hybrid Electric Vehicle is subjected to a variation in steering angle as shown in the Figure 8. This variation in the steering angle would be used to analyse the performance of various Degrees of Freedom and thereby vehicle stability. Figure 9 shows the vertical deflection forces that are acting on all the four wheels due to the effect of the steer angle on the suspension. The HEV Model Analysis/4 and HEV Model Analysis/5 are the effect on the two front suspensions of the HEV while HEV Model Analysis/6 and HEV Model Analysis/7 are the effects on rear suspension. This shows that the deflections are synchronised and the effect of the variation in steer angle is uniform on the set of front wheels and the set of rear wheels based on the direct impact.

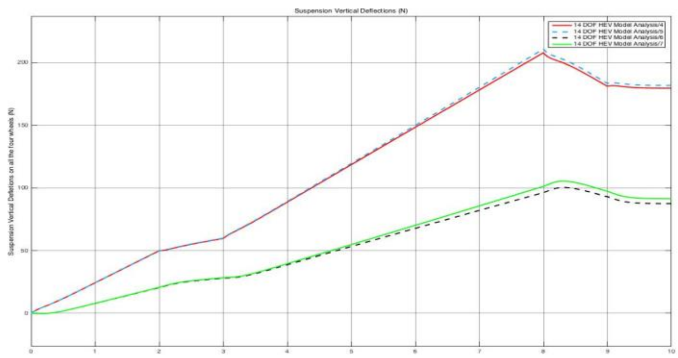

Fig.9: Vertical Deflection forces acting on the wheels due to effect of Steer Angle on the Suspension

Figure 10 shows the variation on the slip angles of the tyres due to the change in steering angle. The slip angle is given by the relation

$$\alpha = \tan^{-1}\left(\frac{v_y}{v_x}\right)$$

which determines the relation of the lateral and longitudinal velocities acting on the tyres.

It can be seen that the HEV Model Analysis/8 and HEV Model Analysis/9 are the slip angles acting on the rear wheels while HEV Model Analysis/10 and HEV Model Analysis/11 are the slip angles acting on the front wheels. The model successfully shows the synchronism between the wheels when subjected to the variation in steer angle.

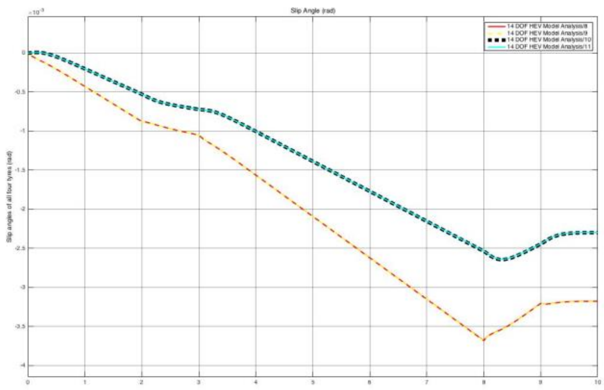

Fig.10: Slip Angles on the tyres due to effect of variation in Steer Angle

Figure 11 details the impact of the variation in steer angle with respect to the yaw angle, roll angle and lateral acceleration. HEV Model Analysis/1 shows the variation in the yaw angle but the roll angle shown by HEV Model Analysis/2 and the lateral acceleration shown by HEV Model Analysis/3 is negligible which implies the model to be able to provide more stability for its passengers.

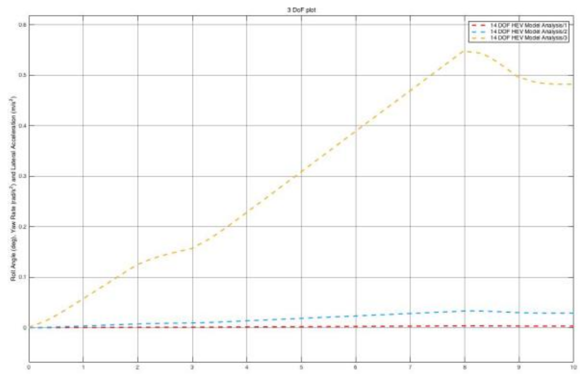

Fig.11: Effect of variation in Steer Angle on Yaw Rate, Roll angle and Lateral Acceleration

II. GPS-GRADIENT LOAD CONTROL

The GPS- Gradient database is used to provide a predictive model with a pseudo optimization approach. Even before the vehicle moves the tentative load sharing pattern between the IC Engine and Motor is available with the controller. A database is developed with the GPS co-ordinates involving the Latitude and Longitude of the path to be followed, mapped with the gradient of the road, the information obtained via online maps or via the inbuilt gyroscope. The inbuilt gyroscope approach is utilized in this work where in the gradient database is created based on the trial run on the road. When the driver first keys in the destination location in the GPS Navigation device inside the vehicle, the coordinates of the starting point and the coordinates of the destination would be extracted and searched in the database. The most optimum path would be decided to travel between the source and the destination.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

The Energy Management System would have the information regarding the most optimum path and also about the gradient of the road even before the commencement of the journey. Based on the road gradient feature the Energy Management System would decide upon managing of power flow from the IC Engine and the Motor. The advantage of this approach is that it prepares an offline optimized operating mode even before the journey and so the Energy Management System could bring about changes as planned. The only factors that would be effective is the road traffic conditions which would be viewed as disturbances or interruptions in the charted path.

The Questar model G702-001UB GPS unit transmits the data through the ESP12- NodeMCU to the cloud platform. The algorithm for receiving the data in reference with the co-ordinates and also the variation in retrieval of data is as described:

• The main header file for the entire process to be solved as codes are mentioned and described.

• A function is declared to enable communication of the digital pins of the micro-processor (software serial NSS(arguments)).

• A function declared to fetch the data from the microprocessor and also store it safe in the cloud for the reference.

• The objects are created for the function and also pin 13 of the microprocessor is declared as output.

• Baud rate of the microprocessor is mentioned.

• Readings are taken, analysed and stored.

The data thus extracted is also interfaced with Matlab which is then used to simulate the setup and analyse its operation using a Matlab/Simulink based model. The control signals generated uses a Fuzzy based controller which regulates the load sharing between the Brushless DC Motor and the IC Engine. The vehicle when goes upon a road with a gradient which keeps on varying the response of the system is shown in Figure 12. The simulation represents the starting of the vehicle at a gradient and so the initial torque required is very high. The battery pack is also checked for SoC. Based on the load sharing control signal from the Fuzzy Controller the Energy Management System shares the load between the Motor and the IC Engine. But considering the level of SoC the IC engine powers the Generator to recharge the battery pack. The characteristics in Figure therefore clearly shows the load sharing between the Motor and the IC Engine. It also shows an initial period where the contribution for IC engine is zero. This is because the IC Engine during this period is not contributing to the propulsion action but is operating the Generator to recharge the battery pack. Once the battery pack retains its stable SoC the IC Engine also helps in the vehicle propulsion based on the load sharing calculated by the controller. To regulate these conditions initially the higher torque demand is met by the Brushless motor while the Generator is powered by the IC engine.

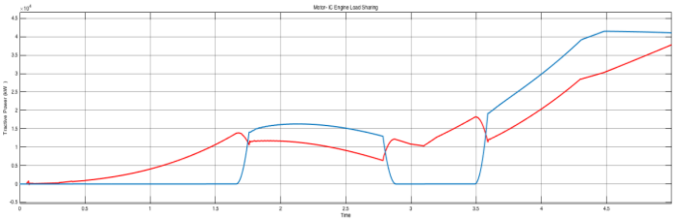

Fig.12: Load sharing on a gradient

Figure 13 shows the situation when the vehicle is cruising on a level road where there is no gradient. During the period when the simulation begins the load sharing occurs with majority of the load taken up by the IC Engine. But initially the SoC of the battery pack is less and hence the IC Engine is not seen to contribute to Vehicle propulsion. The IC Engine is coupled to the Generator through the gear network and powers the battery pack. Once the battery pack is recharged the IC engine starts to contribute to the vehicle propulsion. There around simulation time of 2 seconds it can be seen from the Load sharing curve that the IC Engine disengages from the Generator coupling and starts powering the vehicle propulsion operation.

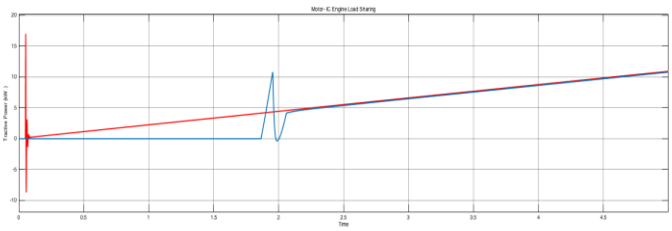

Fig.13: Load sharing on a level road –Cruising mode

The net propulsion power provided by the Motor and the IC engine for a road with a gradient is shown in Figure 14. The net power is sufficient for meeting the tractive power required for the vehicle propulsion considering the various resistive forces acting on the Vehicle while moving up a gradient.

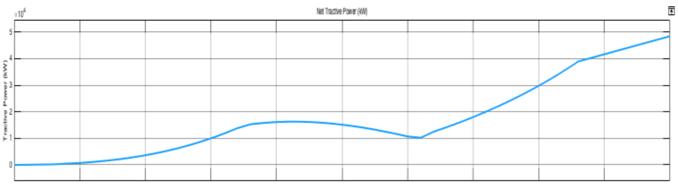

Fig.14: Net propulsion power together from Motor and IC Engine

VI. Conclusion

The paper performs a detailed design and analysis of the performance of a converted Hybrid Electric Vehicle for Indian Driving conditions. The modelling of HEV has been done based on the vehicle dynamic modelling parameters and the packaging and massing has been performed using the Advisor software. The performance comparison of the HEV with respect to the base EV model has been performed based on the dissipation of the SoC of the battery for the WLTC approved Indian Driving Cycle. The analysis showed the HEV to be a better performer for the same driving condition in terms of sustaining the battery SoC.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

The HEV model was further subjected to a dynamic analysis where the variation in steer angle was used as the input to identify the response of the identified 14 Degrees of Freedom of the modelled vehicle. The modelling was performed based on the Ride and handling model [7] and the Pacejka Magic Tyre model. The load sharing between the IC Engine power train and the Electric Motor Power train was performed using a GPS based gradient database. The analysis proved to provide acceptable performance of the modelled vehicle with respect to the vehicle parameter variation and passenger comfort.

ACKNOWLEDGMENT

We take this opportunity to acknowledge the facilities provided by E-mobility Research & Development Facility, Faculty of Engineering, CHRIST (Deemed to be University) for completion of this work successfully.

REFERENCES

1. Assocham India, "Electric Mobility in India: Leveraging collaboration and Nascency", *Ernst & Young LLP*, January 2018
2. "Karnataka Electric Vehicle & Energy Storage Policy 2017", *Commerce and Industries Department, Government of Karnataka*, October 2017.
3. Husain, "Electric and hybrid vehicles: Design Fundamentals." *CRC press*, 2011.
4. Muhammad Ikram Mohd Rashid and Hamdan Danial, "Modelling And Simulation Of Split Plug-In Hybrid Electric Vehicle Using Advisor ," *ARPN Journal of Engineering and Applied Science*s, Vol. 10, No. 21, November 2015
5. Saiful A. Zulkifli, Syaifuddin Mohd, Nordin Saad and A. Rashid A. Aziz , "Operation And Control Of Split-Parallel, Through-The- Road Hybrid Electric Vehicle With In-Wheel Motors ," *International Journal of Automotive and Mechanical Engineering*, Volume 11, pp. 2793-2808, January-June 2015
6. M. F. M. Sabri, K. A. Danapalasingam, M. F. Rahmat , Md Ridzuan and Md Yusof , "Fuel Economy Analysis of Through-the-Road Hybrid Electric Vehicle," *in the proceedings of 10th Asia Control Conference,* pp. 1-6 May-June 2015.
7. Joga Dharma Setiawan, Mochamad Safarudin and Amrik Singh, "Modeling, Simulation and *Validation of 14 DOF Full Vehicle Model," in* the proceeding of International Conference on Instrumentation, Communication, Information Technology, and Biomedical Engineering 2009, Volume 11, pp. 1-6 , 2009.
8. Hans B. Pacejka & Egbert Bakker, "The Magic Formula Tyre Model ," *Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility,* pp. 1-18, August 2007.
9. Joga Dharma Setiawan, Mochamad Safarudin and Amrik Singh, "A 14 Degrees of Freedom Mathematical Model to Predict Car Handling Behaviour on Smooth and Bumpy Roads *," Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility, Taylor & Francis* 2013.
10. Joga Dharma Setiawan, Mochamad Safarudin and Amrik Singh, "Eight Degree of Freedom Vehicle Model with Pitch, Yaw, Tire Control and Sensor Inputs*," California Polytechnic State University*, 2015.

AUTHORS PROFILE

C. Parag Jose is a researcher in the field of E-Mobility. He has published 12 scientific papers. He is currently pursuing his Ph.D from Vellore Institute of Technology and is presently working as an Assistant Professor in the Faculty of Engineering at CHRIST (Deemed to be University), Bangalore India.

Haneesh K.M is a researcher in the field of Control Systems and Electrical Machines. He has 15 years of teaching experience. He is currently pursuing his Ph.D from Vellore Institute of Technology and is presently working as an Assistant Professor in the Faculty of Engineering at CHRIST (Deemed to be University), Bangalore India.

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)