

NUMERICAL ANALYSIS OF HYBRID ELECTRIC VEHICLE

S. Raghuwanshi¹, Ankit Sonthalia², Pramod R. Patel³, N.K. Gahlot⁴

Department of Mechanical Engg. SRM University, NCR Campus, Ghaziabad (U.P)
 Email: sourabh.mechanical@gmail.com¹, ankit.sont@gmail.com², Pramodnitj12@gmail.com³

Abstract— A model for Hybrid electric vehicle power train has been constructed. The HEV model developed is based on the Honda Integrated Motor Assist power-train which is utilized by Honda in its all the HEVs. In order to check the accuracy of the developed MATLAB-SIMULINK HEV model, the simulation is carried out on two different standard international drive cycles (NYCC, WVU5), and the data is compared with the published data. Three major

performance parameters are compared to validate the developed model: fuel consumed, energy regenerated and energy consumed. After comparing the performance parameters the MATLAB-SIMULINK HEV model developed is validated against published data.

Keywords—Hybrid Electric vehicle, Modeling , Simulation, IMA power train

I. INTRODUCTION

The Hybrid electric vehicle combines the advantages of both internal combustion engine and electric motors and remove the disadvantage of higher emissions in conventional vehicles .i.e in terms of improved vehicle performance: fuel economy, emission levels. Another advantage of HEV is the regenerative braking. This is the basic difference between the braking system of a conventional vehicle and HEV. In addition to normal braking system, in HEV the electric motor is utilized to produce negative torque at the axle in order to stop the vehicle. During regenerative braking the part of energy which is dissipated in the form of heat energy from disc or drum in conventional braking systems, is recaptured and fed back to batteries. In order to increase the efficiency and accuracy of automotive design, computer aided engineering is playing a vital role. With the increase in computing powers, manufacturers are now able in designing, testing and optimization using computer simulation prior to the real time implementation of design. Similar to other areas of automotive researches such as vehicle dynamics and crash worthiness, many softwares are developed in order to evaluate the energy efficiencies of conventional vehicles. These softwares are used to simulate conventional vehicles by customizing the power components such as engines and other vehicle components but this software is not good enough for HEV. So there is a need of developing a simple tool dedicated to HEV which can be utilized to simulate complete HEV. The Matlab/simulink model consists of a simple HEV system based on power components and mechanical components of Honda Insight with Integrated Motor Assist (IMA) architecture, in which motor act as an auxiliary power source which assists the engine when engine torque reaches to threshold value. The Honda Insight is chosen as it is the basic power-train utilized by Honda in its all HEV, including Honda Insight (2000), Honda Civic (2005) and it is

also used in Honda Insight Second Generation. And it is also least complex of all hybrid power-train architectures [1].

II. BACKGROUND

The researchers are made to model and simulate the HEV and measuring the major parameters like energy consumed, energy regenerated, fuel consumed. As mentioned above model will be based on HONDA power train i.e IMA technology. Model will be divided into eight parts.

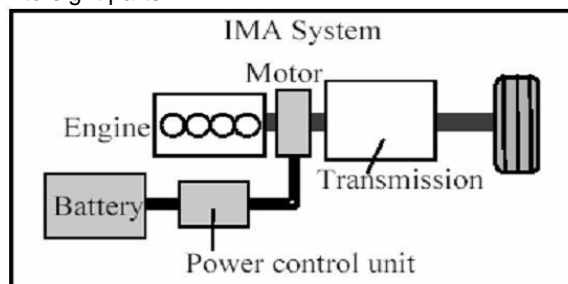


Fig.1. Honda integrated motor assist schematic diagram [6][7]

In IMA as shown in Fig1 a permanent magnet dc brushless motor is placed with direct crankshaft connection between the engine and the transmission. The IMA system uses engine as the main power source while the motor act as auxiliary power source when accelerating. By using motor as auxiliary power source the overall system is compact and simplified. It is possible to use light weight motor, battery, and power controller unit thus reducing the overall weight of the vehicle [3] [4] [5].

III. IMA- HEV CONFIGURATION

The major components of the vehicle utilised in the model development is listed below.

Vehicle mass – 1500 kg

Power control – parallel battery assist.

Motor – permanent magnet dc brushless motor, 10kw

Engine – 1.0 L , 50kw, SI engine

Aerodynamic drag coefficient - .35

Frontal area – 1.9 m²

Air density-1.205kg/m³

Tyre rolling radius-.38m

Transmission-manual, 5 speed

Tires rolling resistance coefficient-.13

IV. METHODOLOGY

Model will be divided on eight small modules .i.e drive cycle, driver controller ,power management controller ,engine ,motor generator, transmission ,battery ,vehicle dynamics. After completing individual modules connect each module in chronological order to form the complete model of Hev.2nd step is to simulate the complete model in order to validate against the published data .

A .Drive Cycle module

The drive cycles means the average speed data which varies with time. There are some drive cycles developed for some common international cities like, New York. Some drive cycles are developed specifically for particular kinds of driving patterns like, driving on high ways, or in traffic etc. and some drive cycles are virtually developed for specific uses. The use of drive cycles is that, without actually driving the real car on that drive cycle, we can simulate our developed model of vehicle on these drive cycles in order to analyze vehicle's behavior on that driving condition. The drive cycles are modeled by using look-up tables indexed by the simulation time. The look- tables consists of speed points for every second. The drive cycles used to simulate the model are EPA-NYCC (New York City drive cycle), West Virginia University 5 peak Drive Cycle (WVU5).

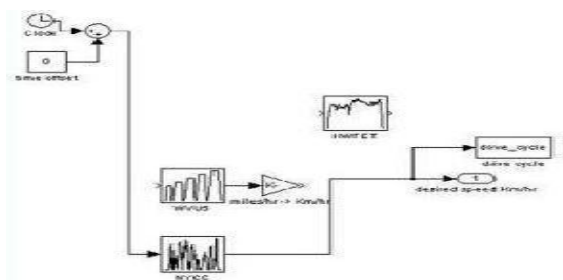


Fig.2.Drive cycle module

B.Driver Controller module

The driver controller module is modeled in order to mimic the behavior of real life driver. Driver decides the intended speed according to that he applies brake or accelator pedal. To model the behavior of driver speed difference between desire speed and vehicle actual speed is calculated. based on these speed difference percent throttle and percent braking is calculated. in this module two swiches are used in order to detect the error. It is shown in fig.3.

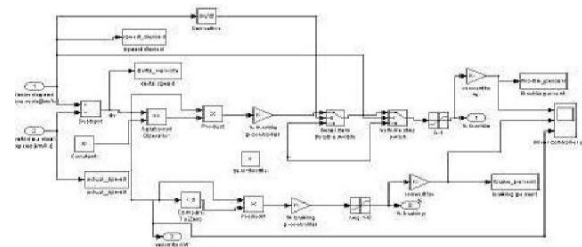


Fig.3 Driver controller module

C. Power Management controller module

The power management controller module is modeled to control the power sources to achieve desired vehicle power while increasing overall vehicle efficiency. The motor can be operated in two modes:

1) *Motor mode*: as in the IMA technology the motor assist is provided, when power desired is greater then maximum power available from engine. In order to activate the motor assist mode all the following conditions should be satisfied:

- The vehicle must be in acceleration.
- The %throttle is considered to be greater then 50% ie 50% throttle open.
- The transmission should be in greater then 1st gear.

1) *Regenerative mode*: in order to capture the energy during deceleration the motor will act as generator in regeneration mode. To activate regenerative mode following conditions must satisfied:

- The vehicle must be in deceleration state.[8]
- The vehicle velocity must be greater then 16 km/hr. as below this speed the traction motor is unable to produce regenerative braking.[1]

c) The %braking is considered to be greater then 5% to activate the regenerative mode for simple braking system.

Further research is required to improve the power management logic to further improve the overall vehicle efficiency.

In power management module the desired power from motor is calculated. Motor mode and regenerative mode is modeled as select. The engine on-off select is also modeled according to the

desired speed. the engine turns on only when vehicle is accelerating.

The maximum available power is calculated as:

$$P_{max} = P_{e,max} + P_{m0,max} \dots (1)$$

Deirsed power is calculated as:

$$P_{des} = PT * P_{max} \dots (2)$$

Motor generator power is calculated as:

$$P_{mo-gen} = P_{des} - P_{e,max} \dots (3)$$

The power management controller is shown in Fig.4

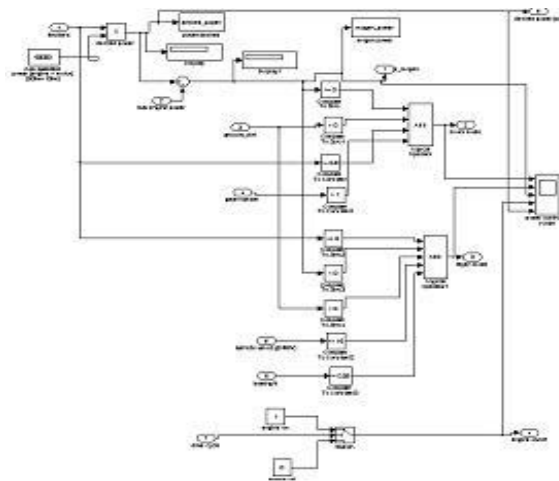


Fig.4. Power Management controller module

D. Engine module

The engine utilised in this module is a 1.0L, 50Kw SI engine. The engine is modeled completely by using lookup tables. The maximum throttle torque (at 100% throttle), closed throttle torque (negative torque felt by the driver after realeasing gas pedal),[8] and fuel rate are modeled as lookup table indexed by engine speed (RPM). Obtained from the transmission module.

The engine fuel rate is modeled as two dimensional lookup table indexed by current engine speed and engine output torque. The fuel consumption is then integrate to obtain total fuel consumed per drive cycle.

The maximum engine torque is calculated as:

$$T_e = PT * (T_{e,max} + T_{e,c}) \dots (4)$$

The maximum engine power is calculated as:

$$P_{e,max} = T_{e,max} * W_e \dots (5)$$

Fuel consumed per cycle is given by:

$$F_{c-c} = F_r * S_s \dots (6)$$

The engine module is shown in fig5

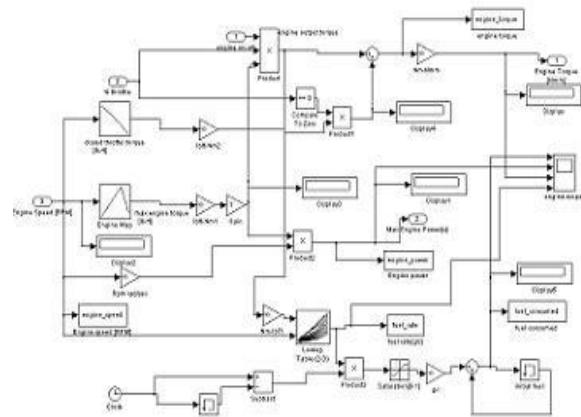


Fig.5 Engine module

E. motor-generator module

The electric motor module is constructed based on 10 Kw DC brushless permanent magnet motor. The motor also act as generator during regeneration mode. The motor-generator module is modeled by look up tables indexed by shaft speed, as in IMA power train, the engine crank shaft is directly connected to the motor shaft. Therefore same engine speed is used for indexing look up tables. During acceleration the output torque of the motor is calculated based on desired power from power management controller and current shaft speed. During regenerative braking the output generator torque is calculated based on maximum generator torque scaled by %braking. The power consumed and generated is calculated by multiplying current motor generator torque and current speed scaled by corresponding efficiency.

The required torque is calculated as:

$$T_r = P_{mo-gen} / W_e \dots (7)$$

The motor torque is calculated as:

$$\text{If } (T_{m0,max} - T_r) > 0$$

$$T_{m0} = T_{m0,max} \dots (8)$$

Else

$$T_{m0} = T_r \dots (9)$$

The generator torque is calculated as:

$$T_{gen} = T_{gen,max} * P_B \dots (10)$$

The net motor generator torque is calculated as:

$$T_{m0-gen} = T_{m0} + T_{gen} + I_m \dots (11)$$

The motor-generator module is shown in figure6.

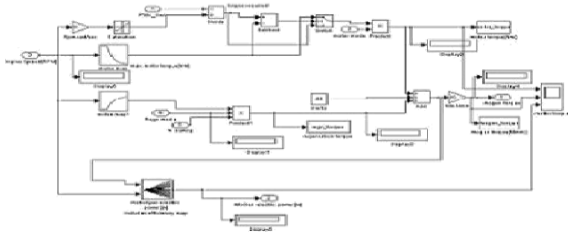


Figure6. Motor-Generator module

F. Transmission modeling

The transmission module constructed is based on 5 speed manual transmission. Simple logic is used to change gears. The transmission is modeled using lookup tables that defines gear ratios indexed by current vehicle speed. the overall ratio is calculated by multiplying gear ratio with final drive ratio. The drive shaft torque is calculated by adding net engine torque and motor-generator torque and multiplying it by overall gear ratio. The engine speed is calculated by multiplying drive shaft speed obtain from the vehicle module with overall gear ratio. The engine idle speed is defined as 900 RPM. In order to increase the overall efficiency of the vehicle engine idle system will automatically off the engine. if the engine speed is less than 900 RPM. Similarly transmission would be disconnected from engine if engine is turned off.

The net torque is calculated as:

$$T_{net} = T_e + T_{mo-gen} \dots (12)$$

Drive shaft torque is calculated as:

$$T_d = T_{net} * N_{tf} \dots (13)$$

Where $N_{tf} = N_t * N_f \dots (14)$

The transmission module is shown in figure7.

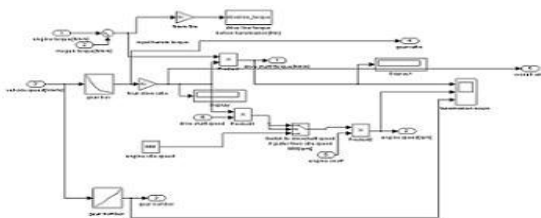


Figure7 Transmission module

G. Vehicle Module

The vehicle module is constructed by using empirical formulae. The vehicle module is corresponding to vehicle dynamics. The major parameters which are modeled in vehicle module are acceleration and velocity [2].

The acceleration is calculated as:

$$A_x = (1 / M * M_f) [(T_d n_{tf}) / r - R_x - D_a] \dots (15)$$

Where M_f is mass factor which is calculated as:

$$M_f = 1 + .04 + .0025 N_{tf}^2 \dots (16)$$

R_x is rolling resistance of tyre calculated as:

$$R_x = F_r (M * g) \dots (17)$$

F_r is rolling resistance coefficient, g acceleration due to gravity.

D_a is aerodynamic drag calculated as:

$$D_a = .5 d A_f C_d V^2 \dots (18)$$

Where d is air density, A_f is frontal area of the car, C_d is aerodynamic drag coefficient V is current vehicle velocity.

The vehicle velocity is calculated as:

$$V = K * (P_{des} / A_x M) \dots (19)$$

Where $K \approx 904.54$, P_{des} is desired power

The drive shaft speed is calculated as:

$$W_d = K * W_e / N_{tf} \dots (20)$$

The vehicle module is shown in figure8.

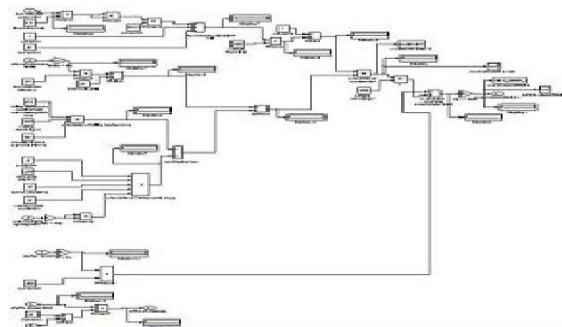


Figure8 vehicle module

H. Battery modeling

The battery utilised in this model is having 6.5 Ahr capacity and 144 v rated voltage. The battery module is modeled by energy calculation. At each time step the energy consumed and energy generated is calculated by integrating motor generator electric power. The energy consumed and generated is calculated at each time step is added or subtracted to energy at previous time step. The new energy is then stored in memory to use in next step. The battery state of charge is calculated by dividing the current energy value by maximum capacity of battery.

Assumptions are made in order to simplify the modeling of battery module:

- 1) The no-load voltage of battery is same at various state of charge.
 - 2) The internal resistance of battery is zero.
 - 3) No-load voltage is equal to rated voltage
- The maximum energy capacity of battery is calculated as:

$$C_{b,max} = C_r * V_r \dots (21)$$

Where C_r is rated capacity and V_r is rated voltage. Energy consumed is calculated as:

$$E_c = \text{integration} [(P_{mo-gen} * \text{motor mode select})] \dots (22)$$

$$\text{Energy regenerated is calculated as: } E_r = \text{integration} [(P_{mo-gen} * \text{regen mode select})] \dots (23)$$

$$\text{Battery state of charge is calculated as: } SOC = C_{b,max} / E \dots (24)$$

The battery module is shown in figure9.

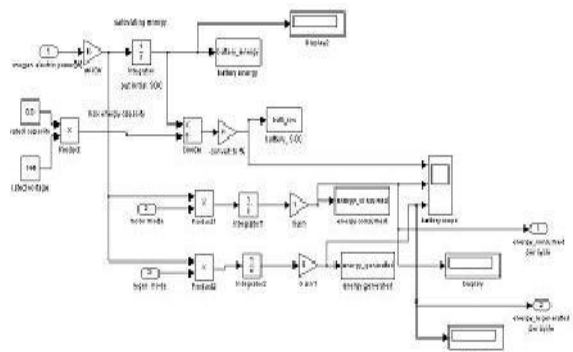


Figure9. Battery module

V. SIMULATION AND EVALUATION

The simulation of HEV on different approximate standard drive cycles is being conducted. The simulation is parametric analysis of HEV

performance.[4][5] The major parameters which are simulated are Energy regenerated per driving cycle and fuel consumed per driving cycle. The approximate driving cycle on which the simulation is performed are EPA NYCC (new york city cycle), West virgia university 5 peak cycle (WVU5).

The simulation results are:

A. Energy regenerated

Energy regenerated in KWhr (kilo watt hour) per cycle on different approximate drive cycle is given in Table I:

TABLE I ENERGY REGENERATED PER DRIVE CYCLE

NYCC(600sec)	WVU5(820sec)
.3992	0.5994

B. Energy consumed.

The energy consumed per cycle for drive cycles in KWhr by HEV is calculated by the model the results are shown in Table II.

TABLE II ENERGY CONSUMED PER DRIVE CYCLE

NYCC(600sec)	WVU5(820sec)
.2968	.7934

C. Fuel consumed

Fuel consumed per drive cycle in Liters (L) on different approximate drive cycle is given in Table III:

TABLE III FUEL CONSUMED PER DRIVE CYCLE

NYCC(600sec)	WVU5(820sec)
.06464	.09908

D. Energy comparison

Energy comparison of HEV model with published data of Honda Insight

TABLE IV ENERGY COMPARISON

DRIVE Cycle	Energy regenerated published	Energy regenerated model	Energy consumed published	Energy consumed model
NYCC(600sec)	.2425	.3992	.2960	.2968

So after comparing ,it is clear that model is almost validated against the published data.Normal discrepancies are obtained because the drive cycle utilised to simulate the HEVmodel is approximate drive cycle not the accurate one utilised by researchers.therefore the HEV model developed in MATLAB/SIMULINK is validate against the published data.

E.Graph obtained

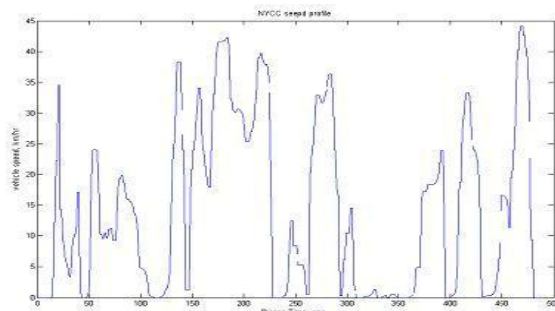


Figure10. NYCC drive cycle

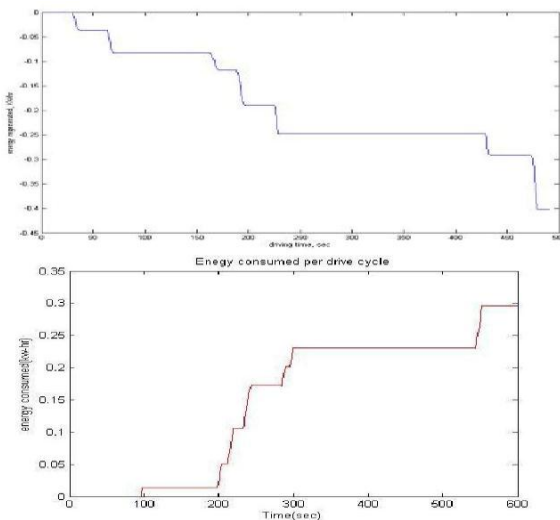


Figure12. Energy consumed by HEV in NYCC

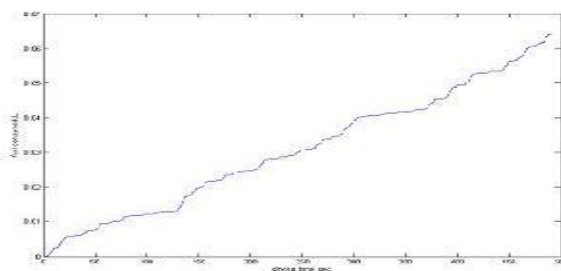


Figure13. Fuel consumed by HEV in NYCC

The hybrid electric vehicle (HEV) model is constructed in MATLAB/SIMULINK based on the Honda Insight Integrated Motor Assist (IMA) power train. The engine utilized is 1.0 L, V-Tec, SI engine and motor utilized is 10 kW permanent magnet DC brushless motor. The data are obtained from the published data of Argonne National Laboratory (ANL) site. The simulation of HEV model is conducted to evaluate the major performance parameters: energy regenerated, energy consumed, fuel consumed. In order to validate the model, the parameters evaluated after simulating the HEV model are compared with the published data of the Honda Insight.

The MATLAB / SIMULINK hybrid electric vehicle (HEV) model provides modular, flexible and easily modifiable platform so that different kind of HEV can be modeled and simulate to virtually investigate there performance prior to the actual manufacturing of the HEV.

REFERENCE

- [1] M.ehsani, Y.gao, S.E.gay, and E. emadi, "Modern electric, hybrid, electric and fuel cell vehicles --- fundamentals, theory and design",CRC press 2005.
- [2] T.D. Gillespie, "Fundamentals of vehicle dynamics" published by SAE inc..
- [3] Yimin gao, Liang Chu, Mehrdad Ehsani, "Design and control principles of hybrid braking systems for EV, HEV and FCV" IEEE vehicle power and propulsion conference 2007. VPPC 2007, PP 384-391, 9-12sept.2007.
- [4] Xiaoling he, Jeffrey w. Hodgson, "modeling and simulation for hybrid electric vehicle-part1: modeling" IEEE transaction on Intelligent transportation systems vol 3 issue 4, dec 2002, pp 235-243.
- [5] Xiaoling he, Jeffrey w. Hodgson, "modeling and simulation for hybrid electric vehicle-part2: simulation" IEEE transaction on Intelligent transportation systems vol 3,no 4, dec 2002, pp 244-251.
- [6] kaoru Aoki, shigetaka kuroda, shigemasa kajiwara, hiromitsu sato and yoshio yamamoto Honda R&D co., Ltd. "Development of Integrated Motor Assist Hybrid system: Development of the Insight a Personal Hybrid Coupe," JSAE no. 2000-01-2216.
- [7] Hirohisa Ogawa, Masato Matsuki and Takahiro Eguchi Honda R&D Co., Ltd "Development of a Power Train for the Hybrid Automobile The Civic Hybrid" JSAE no. 2003-01-0083.
- [8]Kenji Itagaki, Tatsuo Teratani, Kohjiro Kuramochi, Seiji Nakamura, and Takeshi,Tachibana, Hatsuo Nakao and Yusuke Kamijo Toyota Motor Corp "Development of the Toyota Mild-HybridSystem " JSAE no. 2002-01-0990

CONCLUSION