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ISSN: 2322-5114
Journal of World's Electrical Engineering and Technology
J. World. Elect. Eng. Tech. 3(2): 93-98, 2014

JWEET

Implementation of an Optimum Model for Hybrid Electric Vehicles

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Abstract – *Nowadays hybrid electric vehicles are the most efficient technology in transportation industry. They have demonstrated the capability of reducing the energy consumption while maintaining vehicle performance [1]. The main focus of this paper is on simulation of a hybrid electric vehicle based on the information provided by HONDA Company for Insight vehicle. This vehicle is a parallel hybrid vehicle that utilizes IMA system and an engine with 66 pound force power. IMA system uses a DC brushless motor with permanent magnet that is placed between engine and transmission system. The IMA system uses engine as the main source of power while the electric motor is used for acceleration[2]. In this article a model has been developed in MATLAB and dynamic systems has been modelled with ADAMS. This model utilized the Honda Insight with IMA (integrated motor assist) that its characteristics have been published by the company. The accuracy of the MATLAB/ADAMS model has been verified using ADVISOR software. All drive cycles and information used in MATLAB/ADAMS model has been built according to defined model in ADVISOR.*

Keywords: *Hybrid Electric Vehicles, Transportation, ADVISOR.*

ORIGINAL ARTICLE
Received 10 July. 2014
Accepted 04 Aug. 2014

INTRODUCTION

The main focus of this paper is on simulation of a hybrid electric vehicle based on the information provided by HONDA Company for Insight vehicle in ADVISOR software all required information about the vehicle and parts are presented in the related model in ADVISOR. This vehicle is a parallel hybrid vehicle that utilizes IMA system and an engine with 66 pound force power. IMA system uses a DC brushless motor with permanent magnet that is placed between engine and transmission system. The IMA system uses engine as the main source of power while the electric motor is used for acceleration [3].

The control system of the vehicle has been modeled using MATLAB software and dynamic systems like steering, chassis and tires have been modeled in ADAMS. For approving the model, ADVISOR software (ADvanced Vehicle SimulatOR) has been used and results have compared. Similar inputs have been introduced to ADVISOR like vehicle characteristics, similar road specifications. Then the model and outputs have been compared. Outputs are vehicle speed, engine speed, engine torque, generator torque and specific fuel consumption and battery state of charge.

LOGIC CONTROLS OF VEHICLE COMPONENTS

All behavior and parts of the vehicle has been modeled using the MATLAB/SIMULINK software. Details of modeling the parts are described in this session.

Driver control logic

The goal of driver controller is to simulate the behaviour of a real driver. This logic in accordance with requirements of the road (input to model) accelerates the vehicle or presses the brake pedal. To achieve this goal the models compares the difference between actual and desired speed. Two controllers are used to generate the percent throttle and breaking as illustrated in figures 1 and 2.

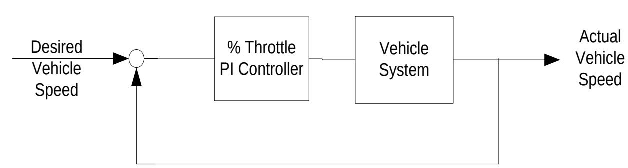

Fig.1.Percent Throttle Closed-Loop PI controller

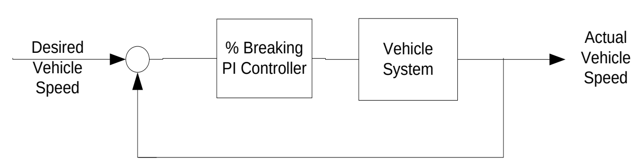

Fig.2.Percent Braking Closed-Loop PI controller

Power management logic

Because one of the most important aspects of hybrid vehicles is their efficiency and it is because of power management module, modeling of this logic can be the most important part of this article. To model this logic it is enough to find the power desired. This value can be calculated based on the percent of throttle and brake using the equation 1.

$$P_{desired} = P_{max} \times \%Throttle \quad (1)$$

The goal of coupling of generator to engine is to assist engine and improve efficiency. The logic used to assist engine and improve efficiency can be seen in Tables 1 and 2 [4].

TABLE 1.
CONTROL LOGIC FOR ENGINE ASSISTING MODE

Engine mode
Transmission gear >1
Desired speed> Actual speed
Percent throttle >50%
Desired power > Max engine power available

TABLE 2.
CONTROL LOGIC FOR REGENERATIVE BRAKING MODE

Generator breaking mode
Desired speed< Actual speed
Percent throttle =0%
Percent braking >5%
Vehicle speed>16km/h
Desired speed< Max engine available power

Brake logic

As mentioned in table 2, regenerative brakeing only activates when vehicle speed is grater than 16km/h and when percent of braking is more than 5% mechanical brakes will activated. Figure 3 shows the logic control of brake.

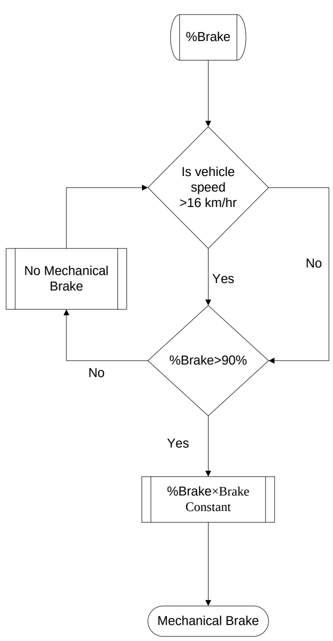

Fig.3. Brake logic control

For this hybrid electric vehicle, two simulation software have been used. As it is discussed earlier powertrain components and logic controls are modeled in MATLAB and mechanical components are modeled in MSC ADAMS. In this session these components are described.

Drive cycle

One of the most important inputs for analysing the hybrid electric vehicle is the drive cycle. It is simulated using the drive cycle used in ADVISOR software[5],[6] because output of the model should be validated with valid software using the same inputs. In figure 4 schematic of the model is illustrated.

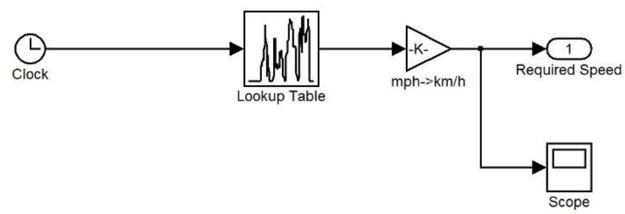

Fig.4. Drive cycle schematic

Driving control

Driving control uses the drive cycle as the main input to accelerate or activate the brake. This module prepares the most important input for other units like power management control that is descried in next session. A model simulation of this part is shown in figure 5.

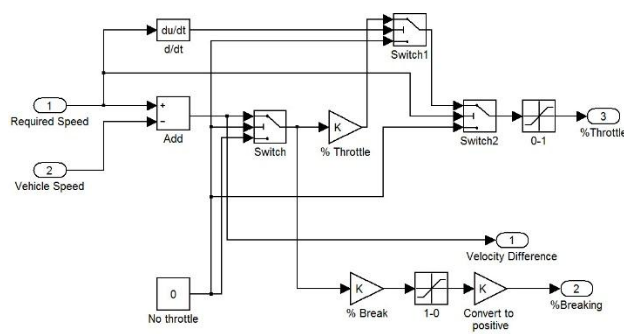

Fig.5. Driving control logic

The output of this control system is braking percent and throttle percent and velocity difference. All these outputs are inputs to power controller that controls the produced power and regenerative braking.

Power management control

This module controls the power and manages it for best efficiency. For example when the vehicle is in stationary status the engine goes off and when the driver decides to move the engine goes on. In all cases the power is calculated by this module using maximum power, multiply by the percent throttle[7]. It is shown in figure 6.

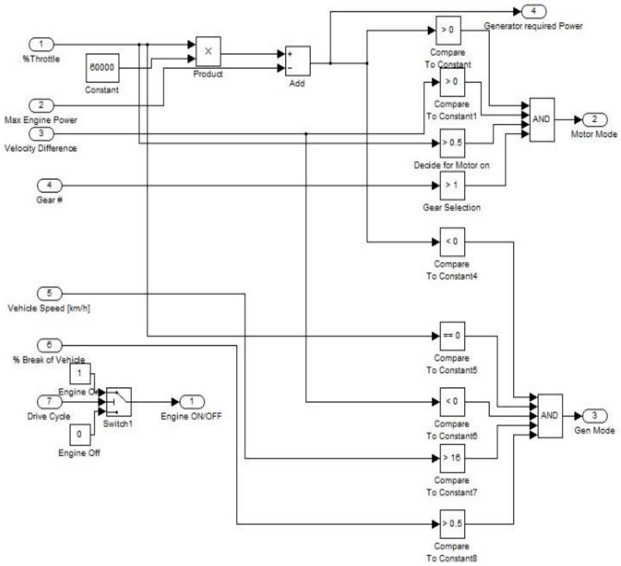

Fig.6. Power controller

Engine

The main task of this module is to calculate the engine output torque based on the throttle percent and speed [8].

TABLE 3.
ENGINE SPEED VS FULL THROTTLE ENGINE TORQUE[8]

Engine Speed [RPM]	100% Throttle Engine Torque [lb-ft]
800	56.9
1273	58.2
1745	59.5
2218	60.7
2691	62
3146	63.2
3636	64.5
4109	65.7
4582	67
5055	64.3
5527	61.5
6000	58.6

TABLE 4.
ENGINE SPEED VS CLOSED THROTTLE ENGINE TORQUE[8]

Engine Speed [RPM]	100% Throttle Engine Torque [lb-ft]
800	-5.15
1273	-8.58
1745	-12.29
2218	-16.28
2691	-20.57
3146	-25.13
3636	-29.97
4109	-35.11
4582	-40.52
5055	-46.23
5527	-52.2
6000	-58.47

This module also calculates the engine fuel consumption as one of the most important criteria for the vehicle (see table 5). The engine subsystem model is shown in figure 7.

TABLE 5
FUEL CONSUMPTION RATE [G/S][8]

	Engine Speed [rpm]			
Engine Torque [lbs]	800	2218	4109	5527
5.6	0.0962	0.1883	0.3112	0.4641
22.3	0.2371	0.4927	0.8334	1.3207
44.7	0.5591	1.0325	1.6637	2.6182
61.4	1.0663	1.8193	2.9448	3.8801

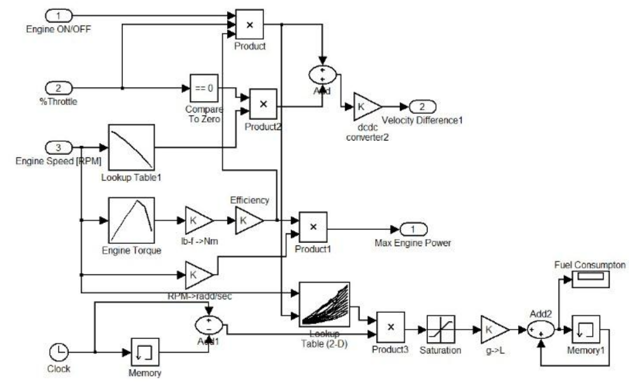

Fig.7. Engine subsystem

Motor/Generator

This subsystem (See Figure 8) calculates the Motor/Generator torque using motor and generator map (see table 6) and efficiency map (see table 7).

TABLE 6
MOTOR AND GENERATOR TORQUE[9][9]

Shaft Speed [rpm]	Max Motor Torque [Nm]	Max Gen Torque [Nm]
0	46.5	-46.5
500	46.5	-46.5
1000	46.5	-46.5
1500	46.5	-46.5
2000	46.5	-46.5
2500	38.2	-38.2
3500	27.3	-27.3
4000	23.9	-23.9
4500	21.2	-21.2
5000	19.1	-19.1
5500	17.4	-17.4
6000	15.9	-15.9
6500	14.7	-14.7

TABLE 7
MOTOR AND GENERATOR EFFICIENCY MAP[9]

	Motor/ Gen Torque [Nm]				
Speed [rpm]	-36	-12	0	20	43.5
0	54.17	66.49	63.07	78.1	63.88
2000	83.36	90.39	81.05	90.42	87.95
4000	93.49	93.45	86.24	95.67	95.88
6000	94.07	93.27	80.69	95.4	95.4
8000	91.27	91.27	76.08	93.49	93.49

Another decision that is taken from this module is a decision if the system is in motor mode or regenerator mode. It means that the system is producing power or charging the battery.

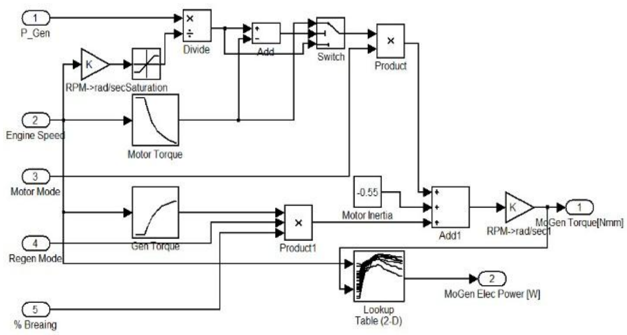

Fig.8. Motor/Generator Subsystem

Mechanical brake

As it is discussed earlier, mechanical brake (See Figure 9) supply the whole torque required when the velocity of the vehicle is less than 16 km/hr and when the velocity is higher than 16km/hr the regenerative mode is activated through braking system.

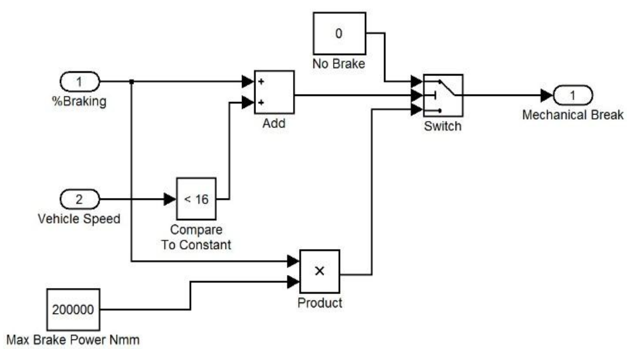

Fig.9. Mechanical Brake

Battery subsystem

In this model the state of charge [10] and initial level at the beginning is defined and based on the power generated or consumed it is updated during the vehicle run (Figure 10).

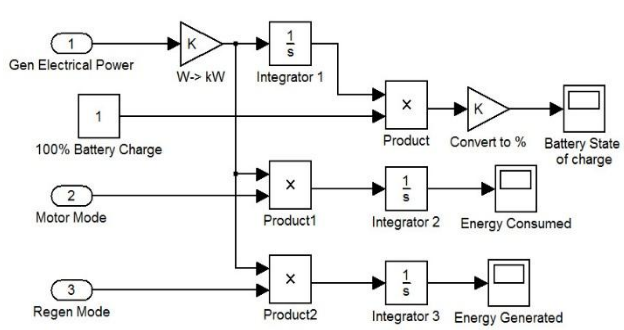

Fig.10. Battery System

ADAMS Subsystem

Mechanical components of the hybrid electric vehicle have been modeled in MSC ADAMS and all properties of tires and suspension are set [11] (see table 7).

TABLE 7
VEHICLE MECHANICAL COMPONENTS

Component	Mass[kg]	Ixx[kg-mm]	Iyy[kg-mm]	Iyy[kg-mm]
Vehicle system	1498	2.95×E9	9.15× $E9$	7.25× $E9$
Tire (each)	20	1.43× $E9$	2.3× $E8$	2.4× $E8$
Steering Rack	9.08	1.3× $E6$	2.1× $E6$	1.43× $E6$
Hybrid Components	100	n/a	n/a	n/a

All other parts are assumed to be rigid. Relation between ADAMS and MATLAB has been defined using standard ADAMS/Control subsystem to communicate with MATLAB.

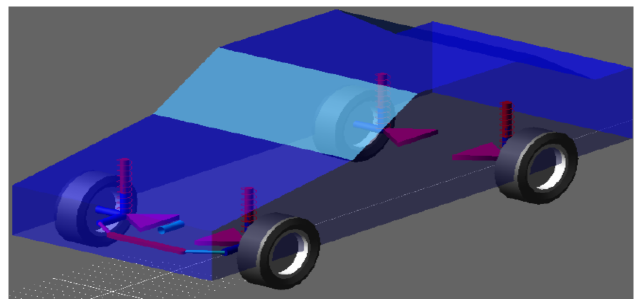

Fig.11. Mechanical components in MSC ADAMS.

RESULTS

To validate outputs of the model, results have been compared with outputs of ADVISOR software. To compare the results the same input has been introduces to ADVISOR and simulated model. MATLAB/ADAMS hybrid vehicle model simulation was performed over 850 second driving cycle named WVU drive cycle that has introduced in ADVISOR as one of the driving cycles for analyzing the behavior of the hybrid vehicles and the results compared.

Vehicle speed

The first parameter that is compared is vehicle speed. As it can be seen in figure 12, two models outputs are the same and almost no difference presents.

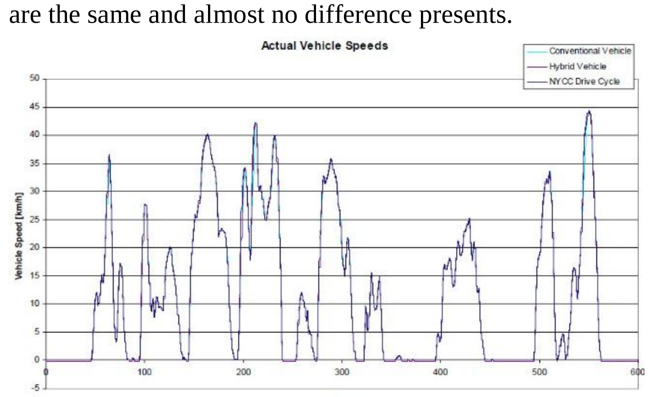

Fig.12. Speed comparison

Engine Torque

Figure 13 shows the comparison of torque engine of two models and as it can be seen the trends are very close but in some cases some differences can be seen. The deviation is in closed throttle situation. As we discussed earlier when the vehicle is in stationary mode the engine will shut off and no torque would be generated. So it seems that the torque that is generated around second 450 in ADVISOR is a software fault that is not shown in MATLAB model.

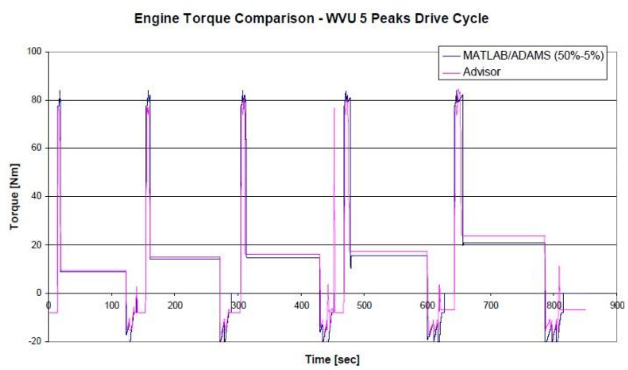

Fig.13. Engine torque comparison

Fuel consumption rate

The most important criteria for a vehicle is fuel consumption rate and all economical and technical comparison would focus on this criteria. In figure 14, this criteria has been compared for the MATLAB model and ADVISOR model and as it can be seen, good compliance exists between two models.

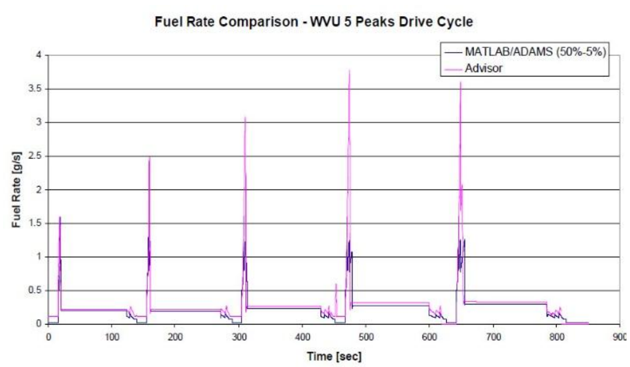

Fig.14. Fuel consumption rate comparison

Battery state of charge

In hybrid electric vehicles, battery state of charge is the most important parameter that makes the vehicle efficient and has a very grate relation with the drive cycle. In figure 15, the battery states of charge of two models are compared. As it can be seen, the results are very close and shows a very good compliance.

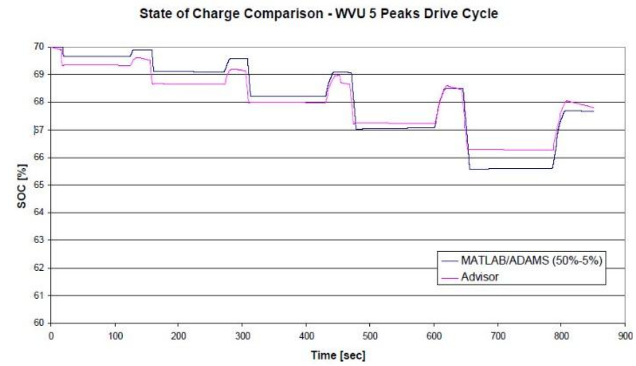

Fig.15. Battery state of charge comparison

CONCLUSION

It is concluded that MATLAB/ADAMS vehicle results matches very well with results of ADVISOR data. So the model can be used to forecast the behaviour of the vehicle for any drive cycles. For furtherer analysis it is recommended that a better state of charge of battery should be used to calculate better and more precise criteria.

Acknowledgements

This paper is the output of research project entitled: "*Modeling and simulation of a hybrid electric vehicle by software*" which is supported financially by Islamic Azad University, Central Tehran Branch according to contract no. 140/201058 and the authors thank IAUCTB for its support.

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