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Study to Enhance Fuel Economy of a Hybrid Electric Vehicle

Hussein Awad Kurdi Saad

Abstract—The studies for hybrid cars have been concerned due to develop alternative techniques to create an alternative energy to a vehicle for decreasing fuel consumption, and limiting exhaust emission created by internal combustion engines. In this paper, a hybrid electric vehicle is simulated with a completely functional driving model. Gaining optimum velocities is done by comparing and identifying two significant velocities. Actual and desired velocities are performed with three cases: Urban Dynamometer Driving Schedule (UDDS), UDDS (Urban Dynamometer Driving Schedule) with 5% grades, and Highway Fuel Economy Driving Schedule (HWFET). Also, miles per gallon gasoline equivalent (MPGe) is designed and implemented to obtain less fuel consuming. So, the MPGe of the hybrid vehicle could be compared with the MPGe for a conventional vehicle. Then, the best MPGe in hybrid car is indicated with a higher effectiveness of producing power.

Index Terms—hybrid vehicle, Fuel economy, plug-in series, Lithium-ion battery.

1 Introduction

ANY two power sources collected together could be considered a hybrid vehicle. likely collections contain gasoline with electric power and any other combinations. Usually, one of the sources is storage energy, and the other is converted a fuel to useful energy to drive a vehicle. The systems of the two separate propulsion could be assisted by the two energy sources together. If it is considered to be a hybrid, two modes of propulsion must be fully possessed by the vehicle [1].
A plug-in series powertrain is used in hybrid-electric cars. To reduce consumption of fuel has been done by emerging as alternative vehicles. A model of a hybrid car could be constructed with a completely functional driving, mobility, and power system models with the Environmental Protection Agency (EPA) drive cycles[2].

The power needed to lead a design of the vehicle could be determined by three schedules: one of them is the EPA's Urban Dynamometer Driving Schedule (UDDS). Another is Urban Dynamometer Driving Schedule (UDDS) with 5% grades. The other is Highway Fuel Economy Driving Schedule (HWFET).

For example, the American Manufacturer General Motors (GM) create the Chevrolet Cruze. Also, the original iteration and a subcompact hatchback are produced by Suzuki in Japanwith joint plan with GM for 7 years. The Cruze sign has indicated to an internationally envolved, built, and manufactured with 4 doors compact sedan, also integrated by 5 door hatchback body since 2008 different from 2011. Logo Holden Cruze in Australasia and Daewoo Lacetti Premiere between 2008 and 2011 in South Korea, the modern generation model does not produce as an alternative model for its Suzuki originated from industry. Instead of substituting other compact models: The Daewoo Lacetti marketed globally under different titles, and the North of USA particular Chevrolet Cobalt. GM removed out product of the Cobalt and its counterpart of badge-engineered, Pontiac (G5) in the year 2010, as the industrialization of the Chevrolet Cruze in America begun[3, 4].In spite plug-in series hybrid vehicles stay a few demands of the market nowadays, electric powertrains are anticipated to be widespread in the year of 2030[5, 6]. The specifications of Chevy Cruze are indicated in Tab. 1

Tab. 1. Chevy Cruze Specifications

J300/Chevrolet Cruze	
Engine	1.8L Ecotec I4
Engine Power	100 Kw
Engine Torque	160 N.m
Gear ratio	1
Suspension (front) (rear)	MacPherson Strusts Torsion Beam Axle
Weight	1500 kg
Wheel Radius, ‘r’	0.33 m
Wheelbase (in)	106.6
Length (in)	181
Height (in)	58.1
Width (in)	70.4
Production	2008-Present
Platform	GM Delta II
Body Style	4-door sedan

2 Simulation Model

An electric mode and a series mode are contained in a hybrid vehicle. There are two sources of electrical power that supply a single electric motor for driving the vehicle. Furthermore, it uses plug-in series hybrid drive.

To illustrate, it can be used some specifications: the capacity of gasoline tank is 60 liters. Also, vehicle weight is 1.5 tons. Moreover, it has a special feature of 1.8L with 4 cylinders. The power can be given with 10 Kw at 6000 rpm and 160 N.m of torque at 3800 rpm.

The source of the unidirectional power fuel tank. Then, this power converter is an internal combustion engine connected to an electric generator. The electric generator has an output power which is linked to a power direct current (DC) bus through a rectifier.

The other source is bidirectional energy. This energy is considered as a battery pack of Lithium-ion battery linked to power direct current bus which could be controlled by a rectifier, and DC/DC converter. In addition, the output bus is coupled to the electric motor controller. The propelling motor could be regulated in modes such as a motor or a generator, and also either in forward or reverse movement. A battery charger may be required by the drive train to charge the Lithium-ion batteries.

The controller is required by the drive train to regulate the running energy flows relied on the motorist's operating order through accelerator and brake pedals from related components. The internal combustion engine will be controlled by the controller during throttle, electric coupler, and propelling motor to form the needed the torque of regenerative braking. Fig. 1 demonstrates a plug-in series powertrain.

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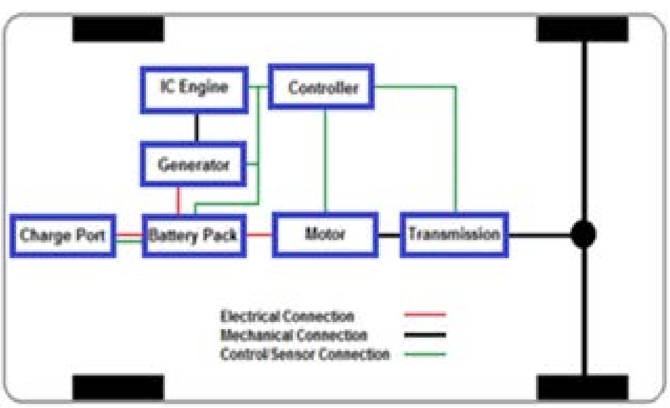

Fig. 1. Plug-in series powertrain

Hussein Awad Kurdi Saad is a full time lecturer at Engineering Technical College of Al-Najaf Al-Furat Al-Awsat Technical University /Iraq
E-mail:husseinawad2@yahoo.com

The engine produces angular velocity which is supplied to the torque converter in automatic transmission. The turbine torque and the impeller torque are the output. Then, utilizing gear selection system is gotten, and the velocity regulates the output force.

3 Subsystem Models

Using to calculate the resulting forces from a desired behavior of a given system is done by Inverse dynamics. the motion is limited and the needed effort variables like forces, torques and pressures are determined by using the inverse model. Why the inverse model is used is to observe how much desired parameters vary from the simulated parameters.

There are two derive cycles are used in this study. the first one is Urban Dynamometer Driving Schedule (UDDS) and the second one is Highway Fuel Economy Driving Schedule (HWFET). These two cycles are utilized to obtain the actual velocities[7].

The desired velocities in this model which are taken from the Urban Dynamometer Driving Schedule (UDDS) data clarify the input, and the tractive force Fx which is used equation (1) appears the output[8, 9].

$$F_X = (m + m_r)a_x + F_{rr} + F_{aero} + F_{grade} \qquad (1)$$

Where m is the vehicle mass, m_r is the rotational inertia mass, a_x is the acceleration, F_{rr} is the rolling resistance (2), F_{aero} is the aerodynamic force (3) and F_{grade} is the force from inclination (4).

$$F_{rr} = \mu_{rr} W \qquad (2)$$
$$F_{aero} = \frac{1}{2}\rho C_d A V^2 \qquad (3)$$
$$F_{grade} = W sin\theta \quad \text{(When applied 5\% grades)} \ (4)$$

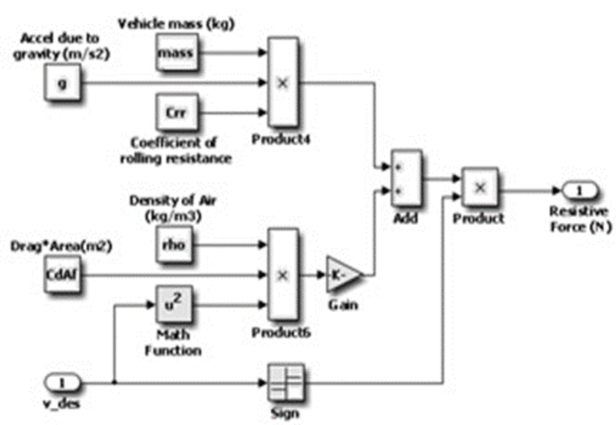

Fig. 2. Resistant Forces (N)

Obtaining initial force (N) is done by calculating the difference between desired velocity and actual velocity divided by time in second and multiplying by the total mass of vehicle. Fig. 3 represents inertia force.

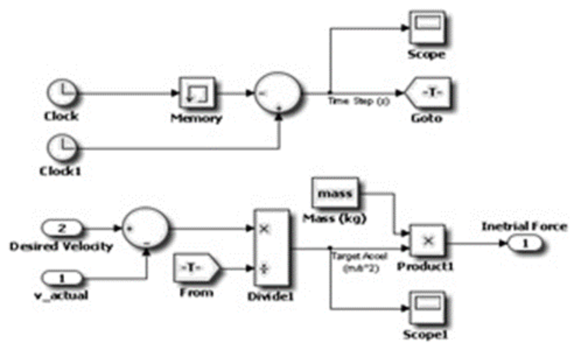

Fig. 3. Inertia Force (N)

In the two previous figures, the subsystem of the model is demonstrated in fig. 4. The actual velocity in the figure, which represented below, comes from forward dynamic. Then, it is combining inertia and resistant forces together; the desired tractive force is going to be possessed. Fig. 4. shows the inverse dynamic model.

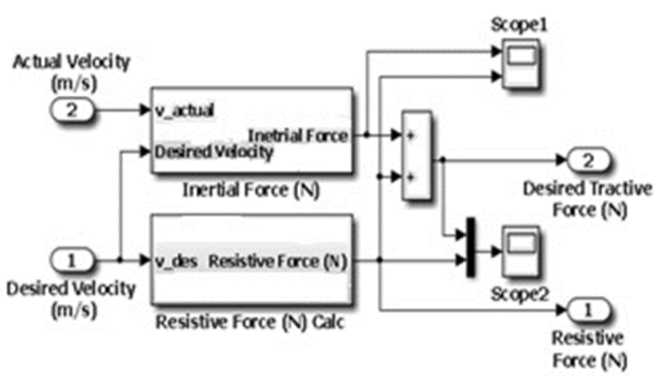

Fig. 4. Inverse dynamic model

3.1 Electric Motor Models

There are three parts can classify electric motor models such as engine torque, engine torque control, and engine speed calculation. In the first model, the desired engine torque is figured by using eq. (5).

$$T_e = \left(\frac{r_{tire}}{GR_t GR_f\, n_t n_f}\right) F_x \quad (5)$$

Where GR_t is the gear ratio, GR_f is the final drive ratio, r_{tire} is the radius of the wheel, their values are indicated in table 1 above. n_t and n_f are the efficiencies for the transmission and final drive respectively, assumed to be 1. Fig. 5. represents engine torque model.

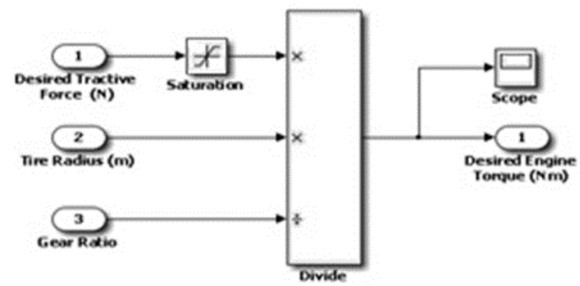

Fig. 5. Engine torque model

Another part is engine torque control. Utilizing desired torque from engine torque model and engine speed calculates actual engine from engine speed calculation. Fig. 6. presents engine torque control

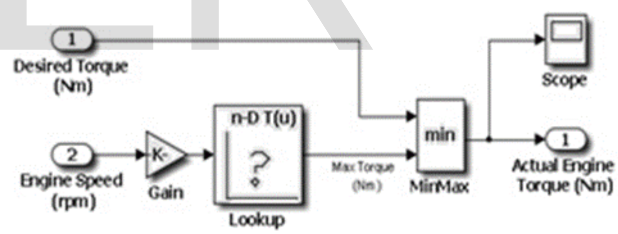

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Fig. 6. Engine torque control

Engine speed calculation is the other part of this model. Eq. (6) can be applied to get the engine speed.

$$\omega = \left(\left(\frac{GR_t GR_f n_t n_f}{r_{tire}}\right)\right) V \quad (6)$$

Where ω is an engine speed in (rpm), V is the actual velocity in meters per second. Fig. 7. offers engine speed calculation.

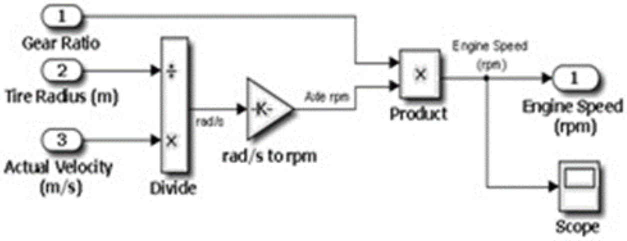

Fig. 7. Engine Speed Calculation

The three parts of models for electric motor could be gathered in one subsystem[2]. The subsystem of electric motor is shown in Fig. 8.

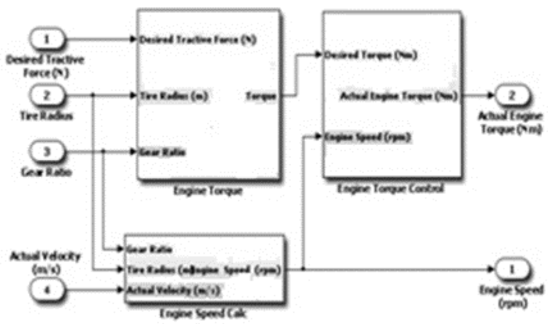

Fig. 8. Electric motor subsystem

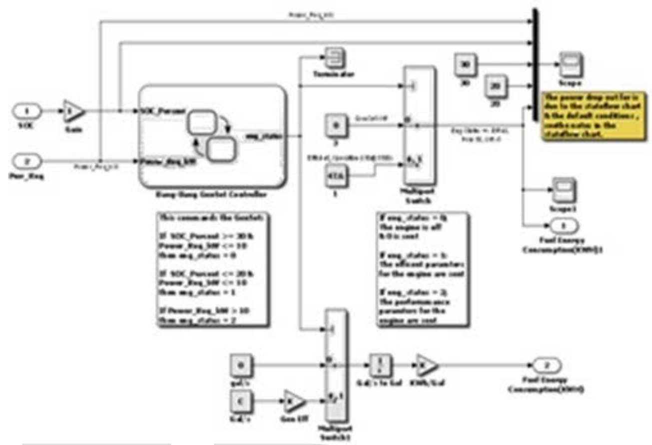

Fig. 10. Genset

3.2Power Calculation Model

The way which can get Power (Kwh) is by calculating engine torque and engine speed from electric motor subsystem. Fig. 9. presents power calculation.

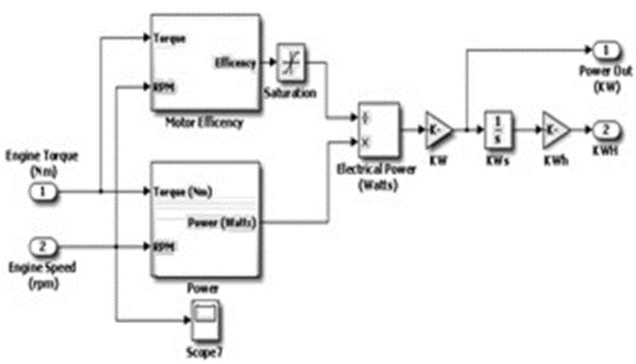

Fig. 9. Power Model

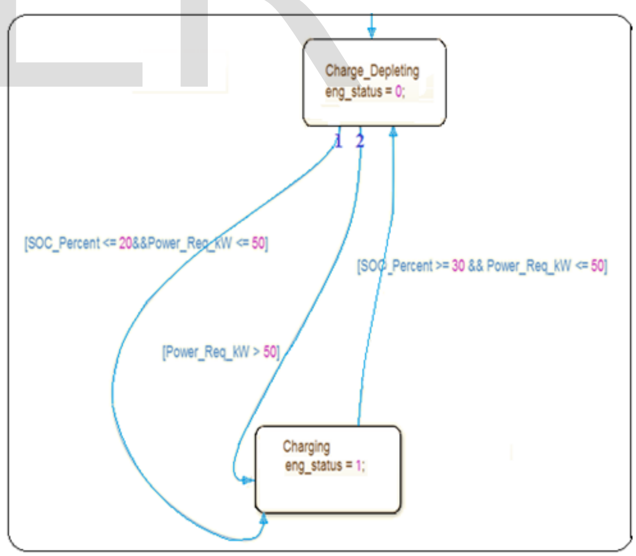

Fig. 11. Genset state flow

3.3Genset

The state of charge and power needed from motor are the inputs of Genset as indicated in Fig. 10. These two inputs will move into a state flow (Fig. 11) to decide engine status. The engine will be turned on when the state of charge is below 30% or the power required is greater than 50kw which is the maximum that battery can provide. The output of state flow will go into a switch: if the genset is on, charge the battery with 47.6 Kw power; if genset is off, no power comes from genset goes into battery.

3.4 ICE Engine

In order to maximum the efficiency, the engine will be operating at a relatively efficient point. The Revolutions per minute of this best efficient point is 3500 RPM with a 130 N.m torque. Furthermore, each time the engine turns on, it should keep running at least 10 seconds.

3.5 Regeneration

The capacity for recovering significant amounts of braking energy is considered one of the most important features of a hybrid vehicle. The electric motor is a vital role in Chevy Cruze which can be controlled to operate as generator to transfer the kinetic or potential energy of vehicle mass into electric energy. This electric energy could be stored in the energy storage and then reused. Normally, the braking torque needed is much larger than the torque which an electric motor could generate especially in heavy braking. In the hybrid vehicle, mechanical friction braking systems have to connect with electrical regenerative braking.Eq. (5) could be used to obtain engine torque in (N.m). After that, eq. (7) could be applied to calculate regeneration power in (Kw) from engine speed in (rpm) and engine torque.

$$P=T.\,\omega \qquad (7)$$

Where P is regeneration power in Kw, T is engine torque in (N.m), and ω is engine speed in (rpm). Fig. 12. presents deceleration or braking model.

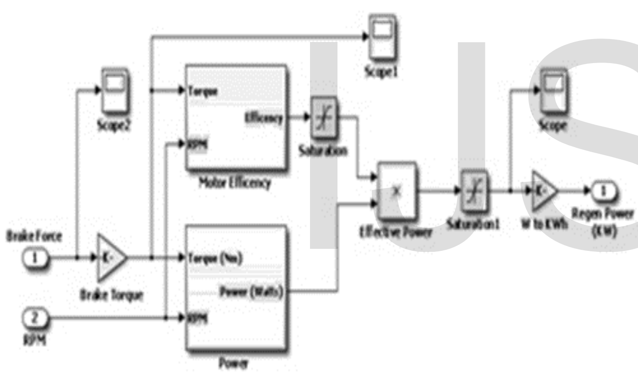

Fig. 12. Braking, Regeneration Model

3.6 Battery Modeling Simulation

The battery utilized isLithium-ion battery. It is used maximum voltage of this battery where it is 402 volts, maximum energy (Emax.) is 3 Kwh, and internal resistance of battery circuit is 2.24 Ohms. As shown in Fig. (13), there are three inputs of battery energy cost. One of them is the power from genest. Another one is the power from regeneration (negative value).
The other is the power cost value at the tractive force. When the power cost value is positive, the battery is depleting mode. When this energy cost value is negative, the battery is at charging mode. In addition, emission can be calculated in this model [2].

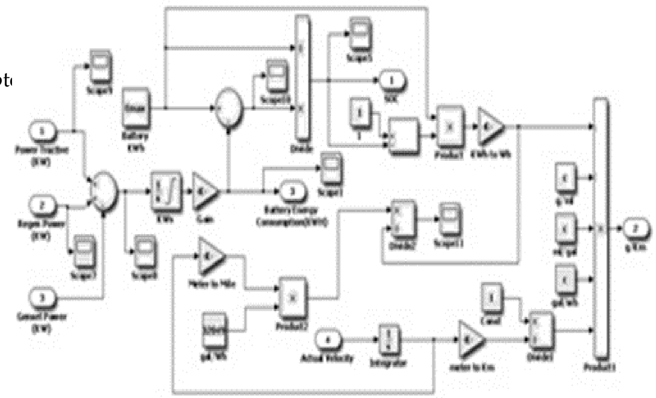

Fig. 13. Battery Model

3.7 MPGe Calculations

The total energy (battery energy and fuel energy) cost into gallons of fuel (E10) is converted that can supply this energy. When it is divided the total distance travelled by this fuel volume, it could get the MPGe indicated in Fig. 14.

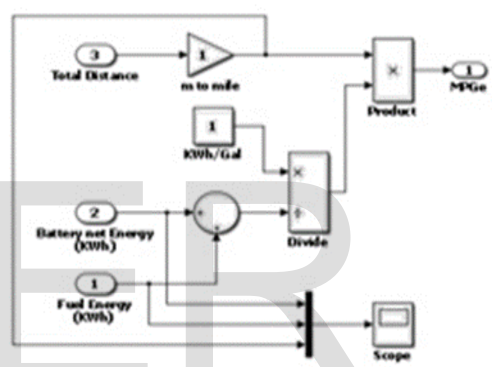

Fig. 14. MPGe

4 Simulation Results

The model presents the charge of sustaining (CS), charge of depleting (CD) and the MPGe for UDDS, UDDS with 5% grade, and HWFET by utilizing utility factor which is equal to 0.2486.
To begin with, rising in the UDDS data demonstrates in the figures below.
For example, the range of UDDS increased to 20.2 Km. Moreover, charge of sustaining (CS) grew precisely 30% more than HWFET which is equal to 41 MPGe. In addition, charge of depleting (CD) increased 108 MPGe.
In contrast, a decline of HWFET can be clearly observed by the figures below.
For instance, a 29.54% reduction in the range which is equal to 15.0 Km was clarified. Moreover, charge of sustaining (CS) decreased to 31.27 MPGe. Furthermore, charge of depleting (CD) reduced to 94.26 MPGe.
As a result, the data certainly indicates the combined values between the UDDS, and HWFET. To illustrate, the range was 17.86 Km. Furthermore, charge of sustaining (CS) and charge of depleting (CD) were 36.638 MPGe, and 101.817 MPGe re-

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spectively.

So, the Miles Per Gallon equivalent sticker with (UF=0.2486) was 43.57.

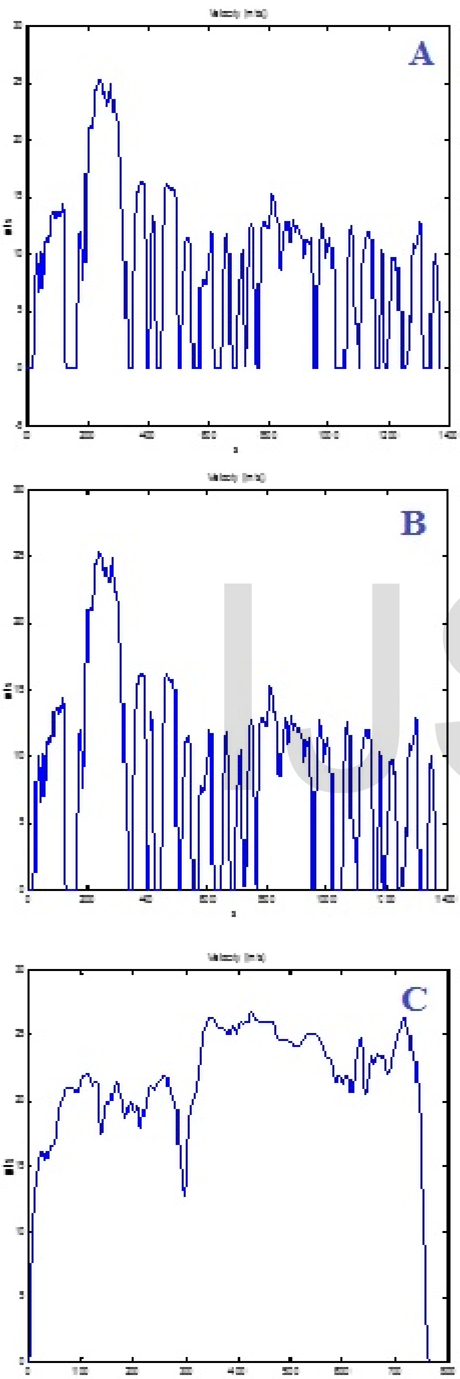

Fig. 15. Actual velocities and Desired Velocity versus time for (A) UDDS, (B) UDDS with 5% grade, and (C) HWFET.

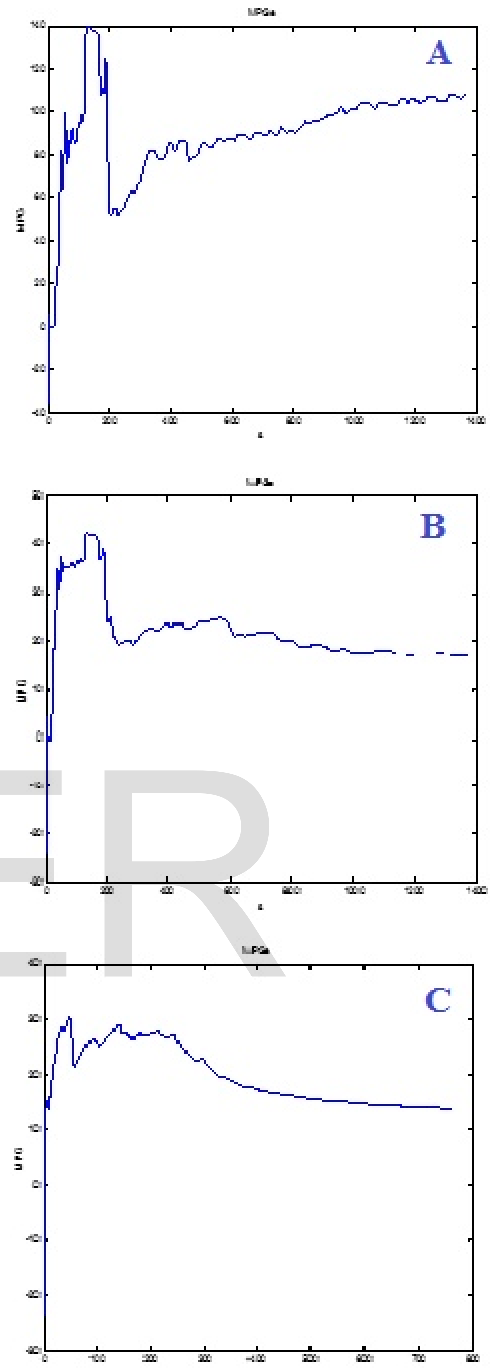

Fig. 16. MPGe versus time (A) UDDS, (B) UDDS with 5% grade, and (C) HWFET.

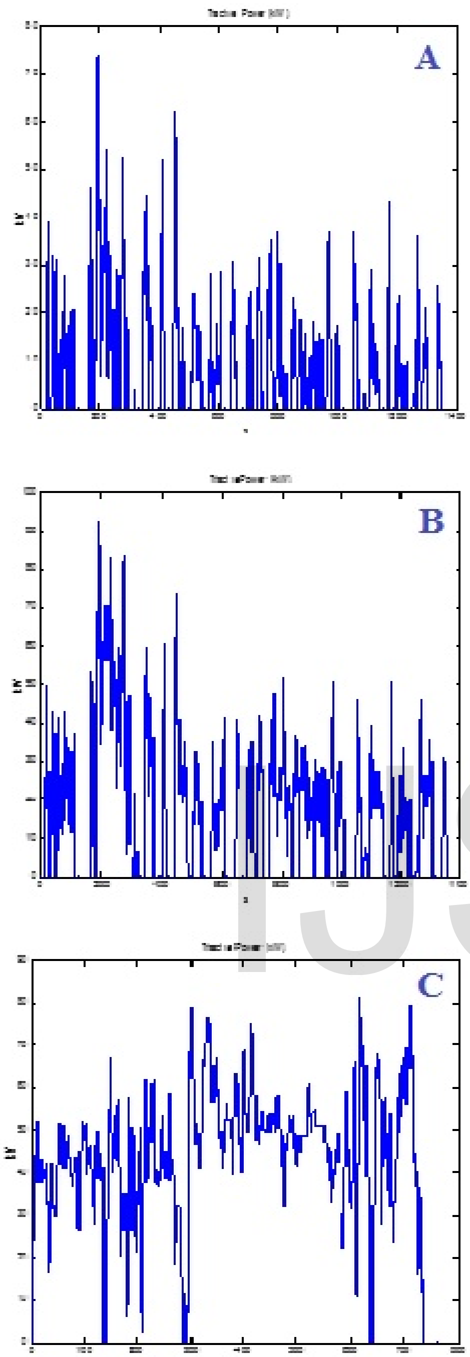

Fig. 17. Tractive Power in (KW) versus time for (A) UDDS, (B) UDDS with 5% grade, and (C) HWFET.

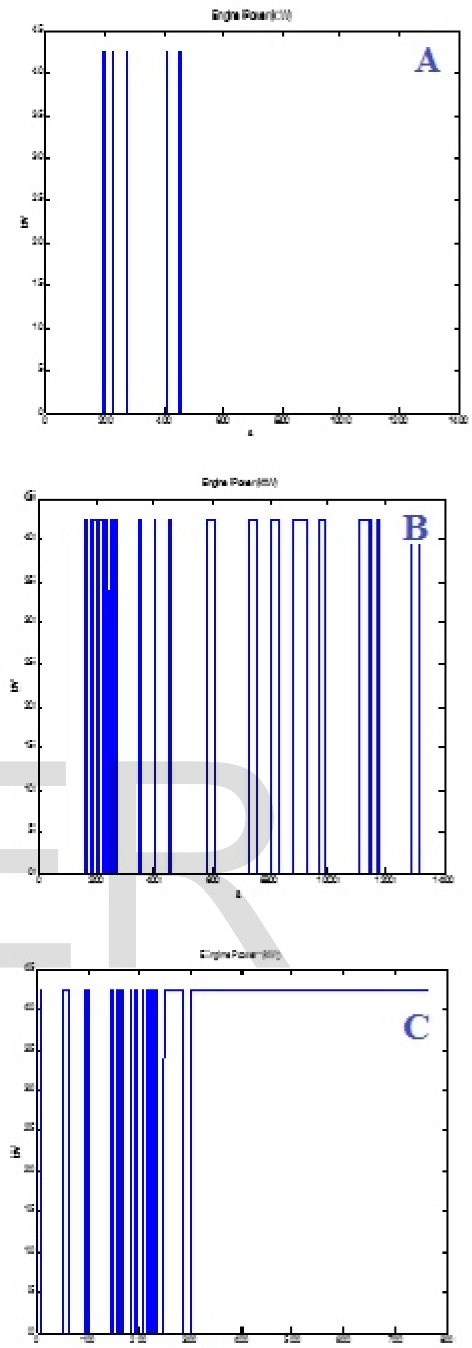

Fig. 18. Engine Power in (KW) versus time for (A) UDDS, (B) UDDS with 5% grade, and (C) HWFET.

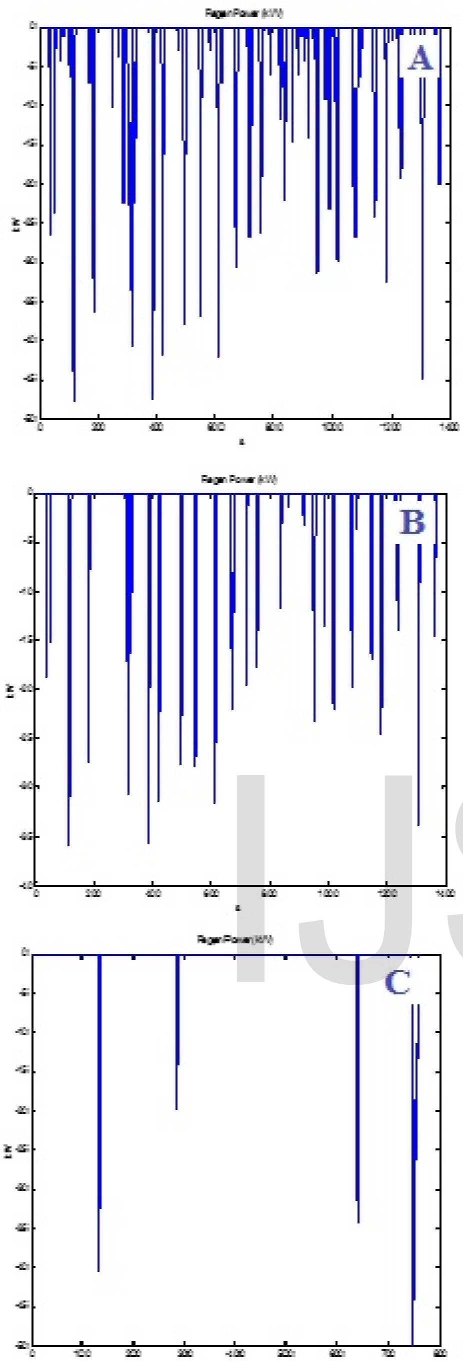

Fig. 19. Regenerative Braking Power in (KW) versus time for (A) UDDS, (B) UDDS with 5% grade, and (C) HWFET.

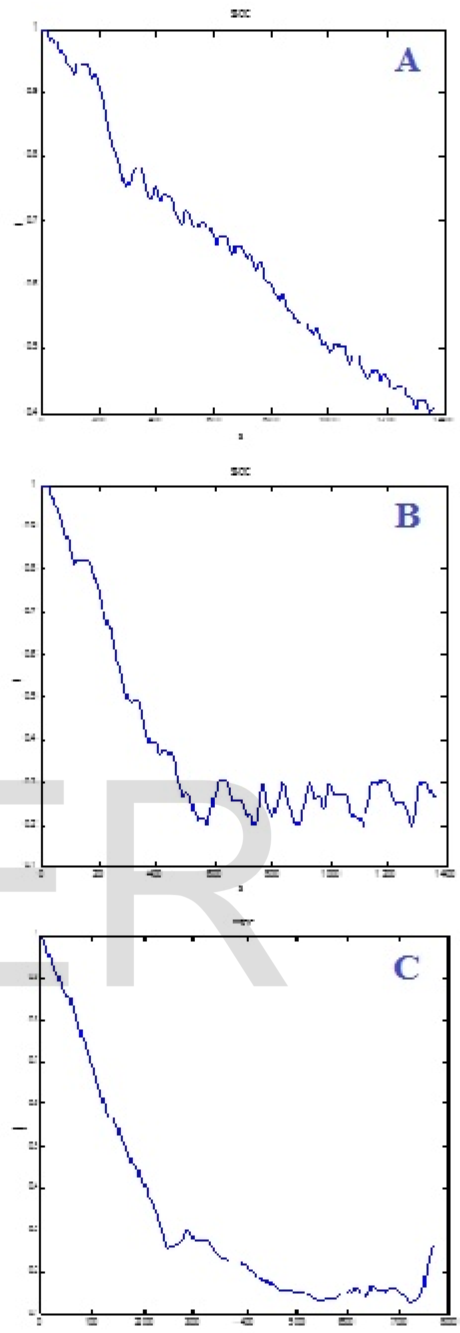

Fig. 20. State of Charge (SOC) for (A) UDDS, (B) UDDS with 5% grade, and (C) HWFET.

The engine will be running at a relatively efficient point. The speed of engine in (rpm) of this efficient point is 3500 rpm with a 130 N.m torque. Moreover, the engine operates on each time, and keeping running at least 10 seconds is advisable. This process is to get maximum efficiency.

CONCLUSION

Presenting a design and simulation of a hybrid electric vehicle with a fully functional driving model is so important. For instance, the comparison between actual velocities and desired velocities in Urban Dynamometer Driving Schedule, and Highway Fuel Economy Driving Schedule is significant to acquire optimum values of a vehicle. Furthermore, calculating MPGe to get less fuel consumption is done by this execution. So, the higher performance of output power for a hybrid vehicle is obtained because it consists of two power modes. One of them is gasoline engine energy, and the other is electric energy.

The electrical energy which is indicated by battery can supply gasoline engine to drive the car, and the engine will charge the battery to prevent the depleting state. Therefore, the hybrid vehicle is better than conventional vehicle for the reasons above in terms performance, less emissions, and fuel economy.

Developing or debugging this model is done by utilizing some parameters such as density of air, gear ratio, coefficient of friction between the wheel tire and road surface, and coefficient of drag. Also, to gain optimum solution is used scope and display for correction the values.

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