AC 2008-2962: DESIGN AND IMPLEMENTATION OF VIRTUAL HYBRID ELECTRIC VEHICLE SIMULATOR FOR EDUCATIONAL PURPOSE

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Design and Implementation of Virtual Hybrid Electric Vehicle Simulator for Educational Purpose

Abstract

The objective of this paper is to describe the development of an educational purpose computer-based simulator for Hybrid Electric Vehicle (HEV) technology. The tremendous capital investment, tedious and time-consuming tasks required to establish a full function of HEV laboratory are convincing evidence that the HEV curriculum is in need of a low-cost, computer-based virtual HEV simulator. An interactive, LabVIEW-based simulation software was developed for different configurations of hybrid powertrains under several driving conditions. The developed software is capable of simulating, illustrating and displaying (on the PC-based screen) the multiple energy flows in the HEV based on its configuration and driving conditions. The software integrated with actuator assembles the simulator which serves as a hands-on experience unit for multidiscipline students enrolled in the HEV technology courses. The virtual HEV simulator not only enhances the HEV training and education, but also increases students' interest in the green movement of transportation.

1. Introduction

World competition and stringent United States fuel economy goals and emission regulations for the 21st Century vehicle have pressured the automotive industry to design and evaluate advanced automobiles at an accelerated rate. The industry consensus is that the hybrid electric vehicle is the currently available technology for increasing propulsion system efficiency and decreasing pollutant emissions [1-2]. However, HEVs operate much differently than conventional vehicles. Therefore, existing design and maintenance techniques and guidelines developed for conventional powertrains do not apply well to hybrid vehicles. There is a need for training automotive technicians and engineers as well as educating students in this new and emergent technology of HEV.

Recently, the Department of Engineering Technology in one university has received a National Science Foundation grant, joint with one community college, to develop courses and degree programs for training community college instructors and automotive technicians in HEV technology. The university developed a set of courses for community college instructors and automotive engineers, and the community college is the first community college in the state – and one of the only in the nation – to train automotive technician students on servicing HEVs [3]. However, no integrated HEV laboratory has yet been established for educational purposes. The tremendous capital investment, tedious and time-consuming tasks required to establish a fully function of HEV laboratory are convincing evidence that the community colleges and secondary schools are in need of a low-cost, computer-based virtual HEV simulator.

The motivation of this project is to develop an interactive, LabVIEW-based [4] simulation software for different configurations of hybrid powertrains under several driving conditions. The

developed software package is capable of simulating, illustrating and displaying (on the PC-based screen) the multiple energy flows in the HEV based on its configuration and driving conditions. The software integrated with an actuator assembles the simulator which serves as a hands-on experience unit for multidiscipline students enrolled in the HEV technology courses. The virtual HEV simulator will not only enhance the HEV training and education, but also inspire students interest in the green movement of transportation.

2. Features of HEV

The potential features of HEV include engine idle stop-start, engine-off driving (pure electric vehicle mode), power boost (maximum acceleration), and energy recuperation (regenerative braking). These typical HEV features are shown in Figure 1 [5]. The virtual HEV simulator uniquely combines all possible functions of HEV, several types of commercially available hybrid powertrain configurations, commonly defined control strategy and driving conditions on a single environment.
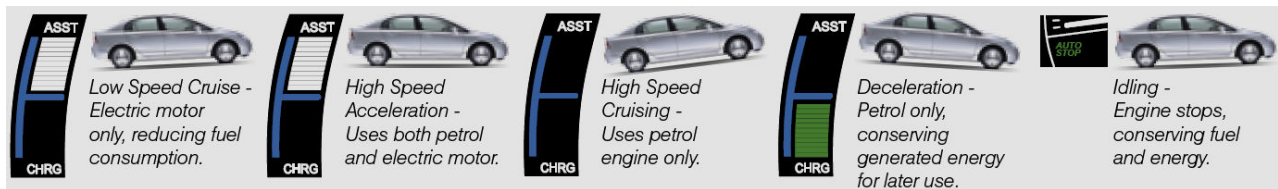

Figure 1. Energy sources in a typical HEV subject to driving conditions [5]

The simulation software comprises two categories in terms of HEV functions: mild and strong HEVs. Each category has several commercially available HEVs. The mild hybrid propulsion systems include Belt Alternator Starter (BAS) [6-8] and Flywheel Alternator Starter (FAS) or Integrated Motor Assist (IMA) [9-10]. The strong hybrid propulsion systems include strong FAS (or IMA) [11-12] and single mode Electrical Variable Transmission (EVT) [13-14]. The above systems are commercially available in today's market, such as Saturn Vue hybrid (BAS), Chevrolet Silverado hybrid truck (mild FAS), Honda Insight, Civic and Accord hybrid (strong FAS), Ford Escape Hybrid and Toyota Prius (single mode EVT).

The features of HEVs including engine idle stop-start, engine-off driving for vehicle launch, power boost, battery charging from engine, and energy recapture (regenerative braking) are implemented in the simulator. The control strategy, which determines the energy flow in the HEV, will be pre-defined and hard-coded in the software. The strategy is based on the commonly implemented in current production type HEVs. The driving condition is input by user through an actuator integrated with the LabVIEW software. This driving condition represents the vehicle speed controlled by the user via vehicle accelerator. Based on the driving condition and pre-defined control rules, the simulator will display the energy flow in the computer screen.

Figure 2 shows the energy flow in a particular HEV [15] under different driving conditions. Similar to the features shown in Fig. 2, the developed virtual HEV simulator is capable of simulating, illustrating and displaying (on the PC-based screen) the multiple energy flows in the HEV based on its configuration and driving conditions.
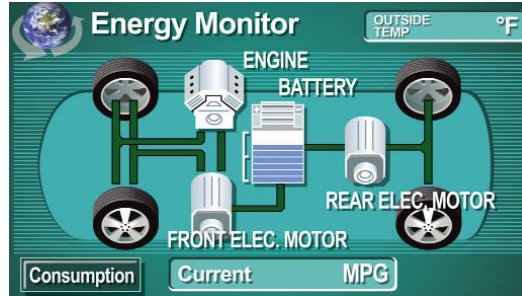
Figure 2. Example of energy flow in a particular HEV [15]

3. Software Development

The software developed in LabVIEW environment is illustrated in this section.

Controls on the front panel
Gasoline Pedal in MPH: It is a vertical pointer slide, and it is used to increase/accelerate the speed of the vehicle as shown in Figure 3. This vertical pointer slide is numbered from zero to 90 mph. Under the gasoline pedal, there is a numeric control that displays the chosen speed digitally and with two decimal numbers.
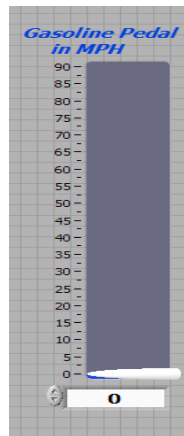

Figure 3. Input speed of vehicle – gasoline pedal

Hybrid Powertrain: As shown in Figure 4, this panel displays the energy flow or selection of power sources in the vehicle. Each function is described next.

Neutral: This push button must be on before start running the vehicle. It does not allow the vehicle to move even if the speed of the vehicle is increased by using the gasoline pedal.

Electric: This function represents the pure electric vehicle mode that vehicle is propelled by electric power only. The vehicle is launched by electric power up to certain pre-defined speed, typically 25 to 35 mph. In this study, this speed is limited to 20 mph so this push button allows

the speed of the vehicle to reach 20 mph only. So if the speed is more than 20 mph, the vehicle's speed will remain at 20mph.

Engine: This push button allows the speed of the vehicle to go from 20 to 60 mph only. So if vehicle speed decreased to less than 20 mph, the speed will remain at 20mph, or if the speed increased to more than 60 mph, the speed will remain at 60mph.

Maximum Acceleration: This push button allows the speed of the vehicle to go from 60 to 80 mph only. So if the vehicle speed decreased to less than 60 mph, the speed will remain at 60 mph, or if the speed increased to more than 80 mph, the speed will remain at 80 mph.
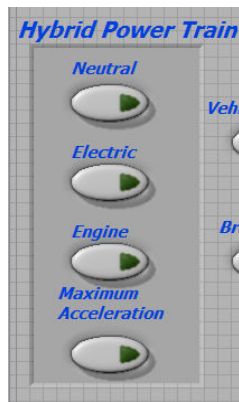

Figure 4. Selection of energy sources in vehicle

Vehicle Key: Figure 5 shows a push button for turning on the vehicle by pressing it only. The program will not run without turning on the button.

Figure 5. Start button as a starting key in vehicle

Brake Pedal: The diagram shown in Figure 6 is similar to the brake in a car. When a driver presses and holds this button, the speed of the vehicle will decrease.

Figure 6. Brake button as a brake pedal in vehicle

Other buttons shown in Figure 7 are Turning Right/Left, Right/Left and Front/Rear Windows. These buttons are only for visualization purpose.

Delay in Seconds: This control button shown in Figure 8 is used to identify how many seconds each loop will take. For example, each loop will take five seconds to execute if this control is set to number 5.

Driving Pattern: An array, shown in Figure 9, consists of thirteen elements, and each element represents time period. The thirteen elements are:
T0:   time required for the vehicle to remain turned on without moving.
T1:   time required for the vehicle to accelerate its speed from 0 to 20 mph.
T2:   time required for the vehicle to stay at a constant speed that is 20 mph.
T3:   time required for the vehicle to accelerate its speed from 20 to 60 mph.
T4:   time required for the vehicle to stay at a constant speed that is 60 mph.
T5:   time required for the vehicle to accelerate its speed from 60 to 80 mph.
T6:   time required for the vehicle to stay at a constant speed that is 80 mph.
T7:   time required for the vehicle to decelerate its speed from 80 to 60 mph.
T8:   time required for the vehicle to stay at a constant speed that is 60 mph.
T9:   time required for the vehicle to decelerate its speed from 60 to 20 mph.
T10: time required for the vehicle to stay at a constant speed that is 20 mph.
T11: time required for the vehicle to decelerate its speed from 20 to 0 mph.
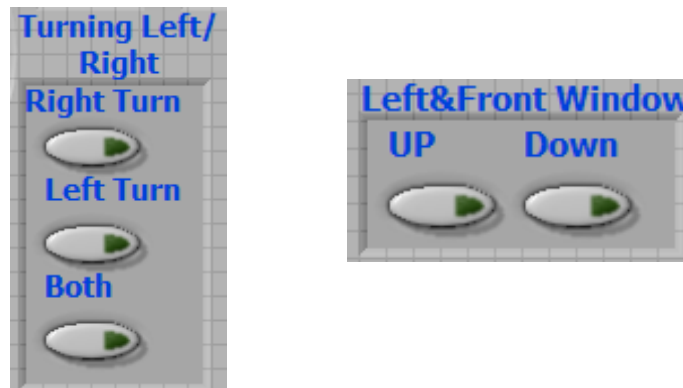T12:   time required for the vehicle to remain turned on without moving.

Figure 7. Other buttons for turning right/left and window up/down
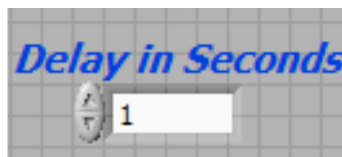
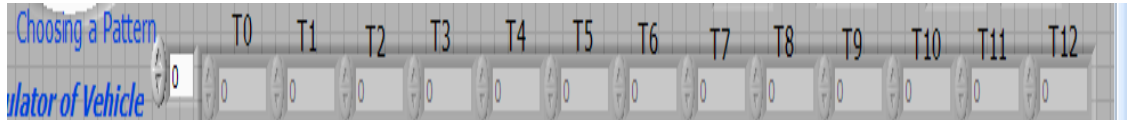

Figure 8. Control button for simulation loops

Figure 9. Inputs of driving patterns

Autonomous: This indicator is used to display the elements of driving patterns as described in previous section. When this button is on, the pattern number will be displayed and repeated until the user presses it off.

4. Display of Results

This section describes the display of results in numeric values, graphs, and Boolean indicators.

Speed of vehicle in mph: This gauge displays the actual moving speed (both analog and digital). In other words, the gauge may display a value different from the one displayed on the numeric control of the gasoline pedal. For example, if the user presses the electric power and set the gasoline pedal to 40 mph, the gauge will display 20 mph, an actual speed of vehicle, and the numeric control will display 40 mph that is different from the gauge's value because the electric drive allows the vehicle speed to reach 20 mph only.

Driving Information: This is a text string displaying the power source and energy flow in the powertrain according to the driving conditions of the vehicle. There are typically five types of energy flows (items b to f) in an HEV, which are the major features of HEVs as shown in Figure 1.
a. The vehicle is turned off:
   Please press the vehicle's key button to turn it on and drive the vehicle

b. The vehicle is turned on, but it is not moving. If you want to move the vehicle, please change to one of the following gear:
   • Electric: accelerate the vehicle from 0 to 20 mph.
   • Engine: accelerate the vehicle from 20 to 60 mph.
   • Maximum Acceleration: accelerate the vehicle from 60 to 80 mph.
   The battery is supplying the electric accessory.

c. The vehicle is moving forward:
   The vehicle is moving by electric motor
   The engine is turned off

d. The vehicle is moving forward:
   The electric motor is acting as generator, and it is charging the battery.
   The vehicle is moving by engine.

e. The vehicle is moving forward:
   The vehicle is moving by the motor and the engine.
   The battery is discharging.

f. The vehicle is decelerating its speed:
   The regenerating brakes are charging the battery

Temperature of Vehicle: This meter shown in Figure 10 displays the temperature of the vehicle. There are five different numbers and the most important are:
0: temperature of the vehicle is cool.
Less than or equal to 25: temperature is normal.
Greater than 25: temperature is getting hot, and in this case it is dangerous to continue driving the vehicle.

RPM: This indicator shown in Figure 11 displays the rpm either of the motor or the engine. There are three cases:
a. 1000 rpm - Neutral or the Electric power is on
b. 2000 rpm - Engine gear is on
c. 3000 rpm - Maximum Acceleration power is on
Other indicators are Brake Light, Moving Lights, and Turning Left/Right Lights. The Brake Light turns on if the Brake Pedal is pressed and held. The Moving Light turns on if the vehicle is accelerating.

Display of Simulator: This indicator displays the trace of vehicle speed with respect to time. An example of simulation results is illustrated in Figure 12 where the X-axis represents the time in seconds and Y-axis represents the vehicle speed in mph. Referring to the Driving Information section, a table illustrating the five types of driving conditions is also shown in Fig. 12.
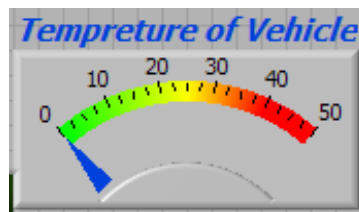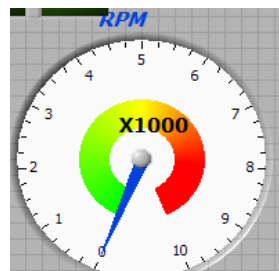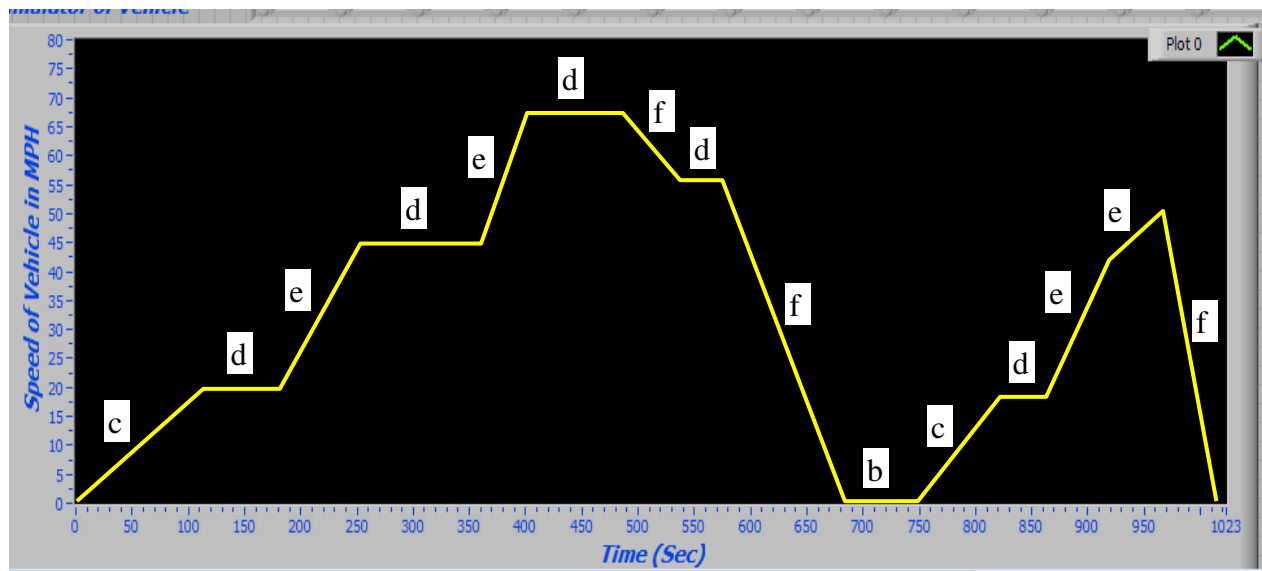

Figure 10. Vehicle temperature gage

Figure 11. Engine or motor speed gage

Condition	Vehicle motion	Energy source	Battery
b	stall	• engine off/fuel cut-off • battery provides electric power to vehicle accessory loads	discharge
c	launched by electric motor – electric vehicle mode	• engine off/fuel cut-off • electric motor moves the vehicle • battery provides electric power to vehicle accessory loads	discharge
d	moving forward by engine power	• engine operating • electric machine acts as generator (driven by engine power)	charge
e	moving forward by both engine and electric machine for maximum acceleration	• engine operating • electric machine motoring	discharge
f	moving forward with deceleration	• engine off/fuel cut-off • electric machine acts as generator (regenerative braking)	charge

Figure 12. An example of driving pattern

Conclusion

Given heightened concerns over the environmental and limited fossil fuels, a clear trend toward hybrid electric vehicles is emerging. There is a clear need for a systematic training program on HEV. This paper describes a funded project whose goal is to develop an educational purpose LabVIEW-based simulator for HEV technology. The tremendous capital investment, tedious and time-consuming tasks required to establish a full function of HEV laboratory are convincing evidence that the HEV curriculum is in need of a low-cost, computer-based virtual HEV

simulator. An interactive, LabVIEW-based simulation software was developed for different configurations of hybrid powertrains under several driving conditions. The developed software is capable of simulating, illustrating and displaying (on the PC-based screen) the multiple energy flows in the HEV based on its configuration and driving conditions. The software integrated with actuator assembles the simulator which serves as a hands-on experience unit for multidiscipline students enrolled in the HEV technology courses. The virtual HEV simulator not only enhances the HEV training and education, but also increases students' interest in the green movement of transportation.

Acknowledgment

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