Abstract—This paper discusses a simulation and modeling package developed at University of Manitoba, REVS: Renewable Energy Vehicle Simulator. REVS assists in detail studies of hybrid electric vehicles (HEV) and plug in HEV (PHEV) configurations or energy management strategies through visual programming by creating components as hierarchical subsystems. REVS is composed of detailed models of seven major types of components: electric motors, internal combustion engines, batteries, chemical reactions, fuzzy control strategies, renewable energy resources and support components that can be integrated to model and simulate hybrid drive trains in different configurations. REVS was developed in the Matlab/Simulink graphical simulation language as well as IDEAS package and is portable to most computer platforms. A series parallel hybrid electric vehicle (HEV) with a conventional internal combustion engine (ICE) and a power split device have been designed using the simulation package. Fuzzy controllers have been developed to track the desired vehicle velocity and manage the energy flow of the vehicle. Simulation results of the energy management system and dynamic responses of the system are discussed for proposed vehicle.

I. INTRODUCTION

Transportation is almost exclusively based on the use of non-renewable fossil fuels. Electricity use for transportation has limited applications because of battery storage range issues, although many recent successful demonstrations of electrical vehicles have been achieved. Renewable biofuels such as biodiesel and bioethanol are only a small percentage of the overall energy sources for mobility. With production of oil predicted to decline, the number of transportation vehicles will not rely exclusively on the use of fossil fuels burnt in an internal combustion engine. Furthermore, the hydrogen fuel cell proposition is not as attractive as first believed, as no gain is possible when the hydrogen is derived from electricity or fossil fuels. It is therefore important to have the ability to simulate different transportation vehicles configurations to enable the optimization of available renewable energy resources and minimize greenhouse gases. Our ability to predict and investigate various transportation pathways can contribute effectively to decrease our reliance on fossil fuels.

Hybrid vehicles offer the promise of higher energy efficiency and reduced emissions when compared with conventional automobiles, but they can also be designed to overcome the range limitations inherent in a purely electric automobile by utilizing two distinct energy sources for propulsion. With hybrid vehicles, energy is stored as a petroleum fuel and in an electrical storage device, such as a battery pack, and is converted to mechanical energy by an internal combustion engine (ICE) and electric motor, respectively. The electric motor is used to improve energy efficiency and vehicle emissions while the ICE provides extended range capability. Though many different arrangements of power sources and converters are possible in a hybrid power plant, the two generally accepted classifications are series and parallel.

Nowadays, researchers focus on understanding the dynamics of the hybrid vehicles by developing the simulators [1]. The results can be used to optimize the design cycle of hybrid vehicles by testing configurations and energy management strategies before prototype construction begins. Power flow management, optimization of the fuel economy and reducing the emissions using intelligent control systems are part of the current research [2]–[5]. Practical and experimental verification of the vehicle simulators is an important part of ongoing researches [6].

Several computer programs have since been developed to describe the operation of hybrid electric power trains [7], including: simple EV simulation (SIMPLEV) from the DOE’s Idaho National Laboratory, MARVEL from Argonne National Laboratory, CarSim from AeroVironment Inc., JANUS from Durham University, ADVISOR from the DOE’s National Renewable Energy Laboratory [8] and Vehicle Mission Simulator [9]. Some of the works conducted by the hybrid vehicle design team at Texas A&M University is reported in papers by Elsani et al. [10]–[12].

The University of Manitoba, Canada, in cooperation with Democritus University of Thrace, Greece, are developing a Renewable Energy Vehicle Simulator (REVS) that enables to simulate renewable energy vehicles using combination of propulsion system and fuels by adapting library modules to suit particular applications. The simulation software predicts the energy use of the vehicle, taking into account the duty cycle and driver habits. Library modules have been developed to simulate the PHEV architecture as this platform offers energy scenario for cars and buses allowing combination of energy sources that include renewable electricity and renewable biofuels. REVS was developed to address the next
generations of vehicles which will not rely exclusively on the use of fossil fuels burnt in an internal combustion engine. The modeling of the internal combustion engines is carried out by IDEAS. The modeling of the transmission system, dynamics of the vehicle, electrical motor and power drivers is done using Matlab and Simulink. REVS simulates different vehicles configurations to enable the optimization of available renewable energy resources and minimize greenhouse gases. This paper discusses the methodology for designing system level vehicles using the REVS package. A series parallel HEV with a conventional ICE and power split transmission system have been designed using the simulation package. A fuzzy controller has been developed to simulate the driver and to command the acceleration and brake pedal. Another fuzzy controller has been employed to manage the power flow in hybrid vehicle. The simulation results are presented for the vehicle.

II. REVS: MODULES AND DESIGN METHODOLOGY

REVS has been developed in Matlab/Simulink environment as well as IDEAS [13], [14]. Mainly, the modules and components related to drive trains, dynamics modeling and control are developed in Simulink and the fluid and heat transfer systems are carried out by IDEAS. The communication module transfers the data between Simulink and IDEAS at each time step. A user can select the components of the vehicle from the libraries and create a specific vehicle configuration. The vehicle can be constructed graphically by connecting the main component blocks (environment, drive cycle, controller, engine, motor/generator, transmission, batteries, vehicle dynamics and renewable energy resources) using the Simulink visual programming methodology through the connection of the appropriate input and output ports. On the other hand, user can set the heat/fluid system components (engine chemical reactions, fuel, solar, fuel cells) using the IDEAS. Energy flow and electrical signals are the main elements transferred between library modules. REVS implements three kinds of controls: direct control, vehicle system level control and component level control. Direct control governs the flow of information from block to block in the model. One block can control another block through output connectors; the same block can be controlled by another block through input connectors. Signal and energy flow from block to block in the model create a direct control network. Results such as engine, motor and vehicle speeds, torque, power and emissions are displayed using the graphical plotting tools that can consider transient responses. Vehicle characteristics such as size and weight, gear ratios, drag and friction coefficients, inertias and the environmental situations can be changed in an excel worksheet file to specify the drive train. A controller block is designed with conventional and fuzzy logic controller blocks which create the signals required to control the individual system-level components. REVS has been designed to be flexible in adding on of more Matlab/Simulink toolboxes for optimization purposes and virtual reality interfaces.

III. DESIGN OF THE SERIES PARALLEL HYBRID ELECTRIC VEHICLE

In this section, the design and analysis of the model of Toyota Prius as a series parallel HEV drive train using the REVS is discussed. The Prius` components such as
ICE, motor, battery, and vehicle dynamics models were defined based on vehicle’s available information. The model of the Power Split Device (PSD) and battery is explained in paper by Liu et al. [15]. A description is given of the performance specifications, the control strategies and power plant developed for the vehicle design. A fuzzy controller is designed to manage the output power of the electric motor based on accelerating pedal and State of the Charge (SOC) of the battery. Another fuzzy controller parallel with a first order system has been employed to model the driver response to the vehicle velocity error. Simulation studies are performed for Prius using two different vehicle velocity drive cycle. Various performance parameters of the vehicle, such as vehicle velocity, SOC and generated power by ICE and EM, during the simulation studies are graphically presented in this paper.

In a typical series parallel drive train design, consisting of an ICE, an electric motor, a generator and a power split device (PSD), either the ICE or the electric motor can be considered the primary energy source depending on the vehicle design and energy management strategy. The PSD divides the output torque of the ICE, with a fixed torque ratio, into the wheels and generator. The output power of the ICE can be divided into an infinite ratio between the wheels and generator. This configuration is designed so that the ICE and electric motor are both responsible for propulsion or each is the prime mover at a certain time in the drive cycle. Also part of the power of the ICE transfers to the wheels while the other is used to recharge an energy accumulator, usually a battery pack. The general schematic of the series parallel configuration in REVS is shown in Figure 1.

Series parallel HEV consists of different elements with various configurations that make the vehicle modeling more complex by providing different number of choices and their effect on a vehicle’s performance for a special mission. The modeling of Prius drive train is shown in details...
in Fig. 2. The ICE model was designed based on Prius torque/power/velocity data and threshold using lookup table. The permanent magnet asynchronous AC motor of the Prius model is also modeled based on available data using lookup table by considering the motor power threshold. Capacity and number of cells of the battery assumed as an initial input parameter in the simulation. State of the charge of the battery and current load determine the DC bus voltage based on battery model [15]. Regenerative braking is inherently performed through PSD and generator whenever the decreasing velocity of the vehicle is demanded by driver. A fuzzy controller manipulates the power contributions of the electric motor that is explained in detail in the following section.

Fig. 3. Schematic of the fuzzy logic power controller with membership functions.

IV. ENERGY MANAGEMENT

The energy management strategy to control the power flow of the vehicle is described in this section. Following criteria should be considered in developing the energy management block: 1- The driver inputs (from brake and accelerating pedals) is consistent with conventional vehicle (driving the series parallel HEV should not “feel” different from driving a conventional vehicle). 2- The state of charge of the battery is sufficient at all times. The power controller determines the power needed to drive the wheels and charge the batteries. It also commands the power required from electric motor. The batteries can be charged at the same time of power assigned to the electric motor. The ICE can provide the power for both charging the batteries and driving the wheels using PSD. The next section discusses the power controller that implements the energy management strategy and uses fuzzy logic to compute the power flow.

A. Power Controller

Figure 2 presents a simplified block diagram of the vehicle model. As shown in Fig. 2, a fuzzy logic controller determines the output power of the EM with regard to the inputs of accelerator pedal and the SOC of the battery. The acceleration pedal signal is normalized to a value between zero and one (zero: pedal is not pressed, one: pedal fully pressed). The normalized braking pedal signal is directly connected to the vehicle dynamic block to subtract braking forces from wheel forces. The output of the power controller block is the scaling factor of the EM power which is normalized between zero and one. The scaling factor is multiplied by the maximum available power of the EM in EM block. On the other hand, the normalized value of the acceleration pedal multiplies by maximum available power of the ICE. Finally, the total power of the vehicle is the ICE+EM power. By this way, the driver can command the complete range of available power at all times. The maximum available EM and ICE power depends on their speed and temperature, and is computed using a 2D look-up table with speed and temperature as inputs of the EM and ICE blocks.

Fig. 4. 3D graph of the fuzzy controller rules for power controller; SOC and Acceleration pedal are inputs and Scaling factor is output.

Fig. 5. Schematic of the fuzzy logic used to model the driver with membership functions.
The EM scaling factor computed through fuzzy logic controller is close to zero when the SOC of the battery is too low. In that case the EM is not used to drive the wheels, in order to prevent battery damage. When the SOC is high enough, the scaling factor equals one. User can change the membership functions of the input and output signals. With respect to the SOC limitations, the scaling factor is proportional to the acceleration pedal. The membership functions of the power control unit are illustrated in Fig. 3. To illustrate the fuzzy logic rules, Fig. 4 shows the scaling factor as a function of acceleration pedal and SOC. As it is shown in Fig. 4, the scaling factor is zero when the SOC is below 0.8.

B. Velocity Tracking Controller

A combination of a low pass filter and a fuzzy controller is assumed to model the driver for tracking the desired velocity. The vehicle velocity error is assumed as the input of the low pass filter of the form \( \frac{1}{0.05s+1} \). On the other hand, a fuzzy controller, parallel with the first order system, commands the acceleration pedal. The membership functions of the driver fuzzy controller have been shown in Fig. 5. When the velocity of the vehicle is lower than desired one, the driver fuzzy controller sets a positive value for acceleration pedal and the more velocity error the more acceleration pedal. The functionality of the rules of the driver fuzzy controller has been shown in Fig. 6.

V. SIMULATION RESULTS

The vehicle has been simulated with REVS by velocity commands. The parameters of the vehicle are listed in Table 1. Two different sets of the desired vehicle velocity are applied on the model to examine the response of the system. The first case examines the vehicle on acceleration, cruise and deceleration and the results are shown in Fig. 7. The second case is a random desired vehicle velocity that includes the sharp accelerations and decelerations. By specified parameters of the system, the desired vehicle velocity shown by solid line, actual vehicle velocity shown by dashed line, SOC, scaling factor, acceleration pedal, electric motor power in KW, ICE power in KW and generator power in KW are shown in Fig. 7 and 8 for first and second cases respectively. As shown in Fig. 7 for the first case, the vehicle can reasonably track the desired velocity. It has also shown that the SOC is kept higher than 0.8. In addition, ICE provides the main power to the vehicle during the cruise period that is highly desirable. It can be seen that the SOC increases during deceleration period that is also one of the important factors in hybrid electric vehicle designs to regenerate the power. The results of the second case in Fig. 8 show that the battery was operated at a relatively high SOC (between 0.75 and the maximum 0.96) for the whole period of driving cycle. It also demonstrates that the controller is well defined to minimize the velocity error. The time period of 10 sec to 30 sec shows the inherent limitation of the vehicle available power that causes large vehicle velocity error. For proposed time period, the power fuzzy controller commands the maximum acceleration pedal and respectively the maximum available EM power has been used by considering the limitation of the SOC. Fig. 8 shows that by reducing the SOC, ICE is the major source of energy for acceleration of the vehicle.
A renewable energy vehicle simulator REVS, for modeling, simulation, and analysis of a drive train developed at University of Manitoba using Matlab/Simulink/IDEAS has been presented in this paper. The goal of REVS is to study issues related to plug in hybrid electric vehicle design such as dynamics, energy management, fuel economy. REVS provides new libraries to model different vehicle configurations in addition to Matlab/Simulink standard toolboxes. The design of a series parallel electric vehicle, Toyota Prius, is presented. Fuzzy controller has been used to control the power flow as well as to track the vehicle velocity. The results of velocity tracking performance, SOC, acceleration pedal commanded by fuzzy controller and electric motor command are illustrated to show the flexibility of the REVS for studying various issues related to electric and hybrid EV design.

VI. CONCLUSIONS

A renewable energy vehicle simulator REVS, for modeling, simulation, and analysis of a drive train developed at University of Manitoba using Matlab/Simulink/IDEAS has been presented in this paper. The goal of REVS is to study issues related to plug in hybrid electric vehicle design such as dynamics, energy management, fuel economy. REVS provides new libraries to model different vehicle configurations in addition to Matlab/Simulink standard toolboxes. The design of a series parallel electric vehicle, Toyota Prius, is presented. Fuzzy controller has been used to control the power flow as well as to track the vehicle velocity. The results of velocity tracking performance, SOC, acceleration pedal commanded by fuzzy controller and electric motor command are illustrated to show the flexibility of the REVS for studying various issues related to electric and hybrid EV design.

VII. ACKNOWLEDGMENT

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REFERENCES


TABLE I
PARAMETERS USED IN PAPER.

<table>
<thead>
<tr>
<th>Definition</th>
<th>Values</th>
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<tbody>
<tr>
<td>Curb weight</td>
<td>1600 Kg</td>
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<tr>
<td>Battery Capacity</td>
<td>10 KWh</td>
</tr>
<tr>
<td>Max ICE power</td>
<td>57 KW 5,000 r.p.m.</td>
</tr>
<tr>
<td>MAX ICE torque</td>
<td>115 Nm 4,200 r.p.m.</td>
</tr>
<tr>
<td>EM power</td>
<td>50 KW 1200 - 1540 r.p.m.</td>
</tr>
<tr>
<td>Maximum voltage</td>
<td>500 V</td>
</tr>
<tr>
<td>Maximum EM torque</td>
<td>400 N.m - 1200 r.p.m.</td>
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