MODELLING AND SIMULATION OF SPLIT PLUG-IN HYBRID ELECTRIC VEHICLE USING ADVISOR

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ABSTRACT

With increasing concern over the environment and ever stringent emissions regulations, the electric vehicle has been investigated as an alternative form of transportation. However, the electric vehicle suffers from relatively short range and long charging times and consequently has not become an acceptable solution to the automotive consumer. The addition of an internal combustion engine to extend the range of the electric vehicle is one method of exploiting the high efficiency and lack of emissions of the electric vehicle while retaining the range and convenient refueling times of a conventional gasoline powered vehicle. The term that describes this type of vehicle is a hybrid electric vehicle. Many configurations of hybrid electric vehicles have been designed and implemented, namely the series, parallel and power-split configurations. This paper discusses the modeling and simulation of split plug-in hybrid electric vehicles. Modeling methods such as physics-based Resistive Companion Form technique and Bond Graph method are presented with powertrain component and system modeling examples. The modeling and simulation capability of existing tools such as ADvanced VehIcle SimulatOR (ADVISOR) is demonstrated through application examples. Since power electronics is indispensable in hybrid vehicles, the issue of numerical oscillations in dynamic simulations involving power electronics is briefly addressed.

Keywords: split-hybrid, plug-in hybrid, ADVISOR

INTRODUCTION

A hybrid electric vehicle draws its propulsion power from an (Internal Combustion Engine) ICE and an electric motor, which can also operate as a generator to charge the onboard electrical energy storage device. Depending on the connectivity of the power sources to the load (wheels), the HEV may have one of the following drivetrain configurations: series hybrid, parallel hybrid or combined series-parallel hybrid [1].

A series-hybrid Figure-1 only has the electric motor turning the drive-shaft while the ICE serves as an on-board electric generator to charge the batteries and/or to power the motor directly ('series' connection between the ICE the electric motor, resulting in an electric transmission of power to the wheels)[1].

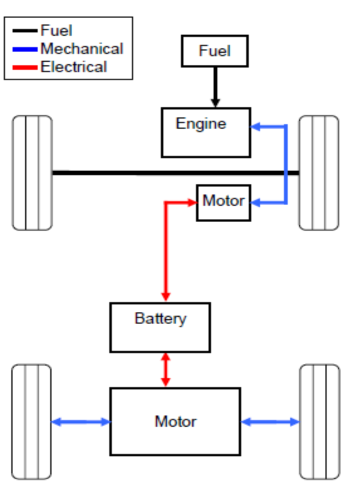

Figure-1. Series-hybrid electric vehicle [2].

Instead, a parallel-hybrid vehicle Figure-2 has the ICE turning the drive-shaft, just like a conventional vehicle, but the drive-shaft can also be turned by the electric motor ('parallel' connection of the ICE and motor to the drive shaft via some form of mechanical coupling and transmission) [1].

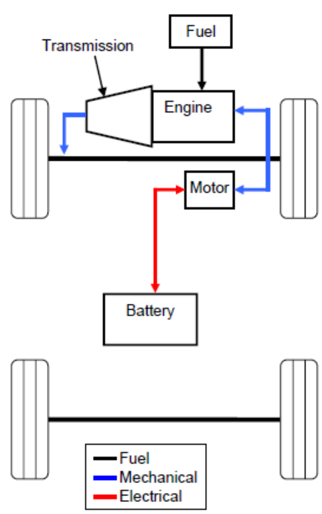

Figure-2. Parallel-hybrid electric vehicle [2].

A hybrid vehicle typically has the motor-generator onboard the chassis, as in most production hybrids of today, the parallel "through the road" hybrid uses one motor for propulsion assist or to recharge the battery by loading the rear axle with the motor. In contrast, the series hybrid provides power to the wheels by a series path of energy conversion through the engine to the

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generator, battery, then the rear motor. Note that the series hybrid and through-the-road parallel hybrid can still propel the vehicle without the engine on, sourcing power for the rear motor from the battery [2].

In this paper addressed about how to model split hybrid electric vehicle and simulate it using ADVISOR. All simulation was done by using ADVISOR and the results were discussed through this paper.

HEV MODELING USING ADVISOR

ADvanced VehIcle SimulatOR (ADVISOR) is a modelling and simulation tool developed by U.S. National Renewable Energy Laboratory (NREL) [4], [5]. It can be used for the analysis of performance, fuel economy, and emissions of conventional, electric, hybrid electric, and fuel cell vehicles. The backbone of the ADVISOR model is the Simulink block diagram shown in Figure-3, for a parallel HEV as an example. Each subsystem (block) of the block diagram has a MATLAB file (m-file) associated with it, which defines the parameters of that particular subsystem. The user can alter both the model inside the block as well as the m-files associated with the block to suit the modeling needs. For example, the user may need a more precise model for the electric motor subsystem. A different model can replace the existing model as long as the inputs and the outputs are the same. On the other hand, the user may leave the model intact and only change the m-file associated with the block diagram. This is equivalent to choosing a different make of the same component (for example choosing a 12-Ah battery manufactured by Hawker-Genesis instead of a 6-Ah battery manufactured by Caterpillar). ADVISOR provides modeling flexibility for a user.

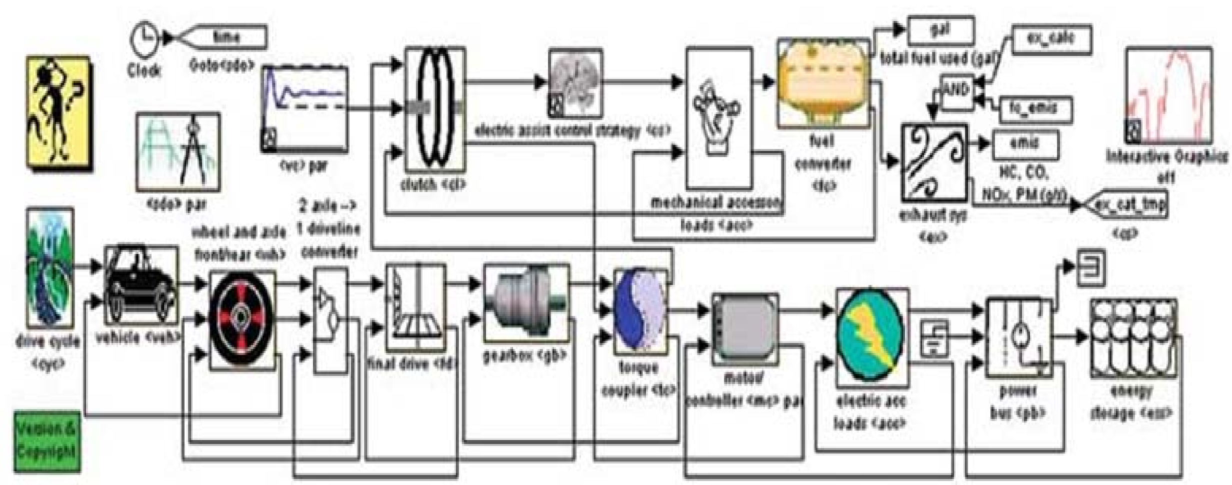

Figure-3. Block diagram of parallel HEV in ADVISOR [3].

ADVISOR models fit empirical data obtained from the component testing to simulate a particular subsystem. In general, the efficiency and limiting performances define the operation of each component. For example, the ICE is modelled using an efficiency map that is obtained via experiments. The efficiency map of a Geo 1.0 L (43 kW) engine is shown in Figure-4. The maximum torque curve is also shown in this map. The engine cannot perform beyond this maximum torque constraint. Maximum torque change is another constraint to the engine subsystem. In other words, the model considers the inertia of the component in the simulation.

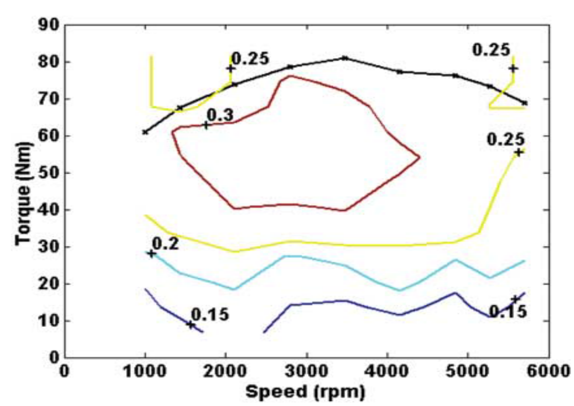

Figure-4. Geo 1.0 L (43 kW) SI engine efficiency map model [3].

The program also allows for the linear scaling of components. For an ICE, this means linear scaling of the torque to provide the required maximum power. This type of scaling is valid only in the neighborhood near the actual parameter where the efficiency map for a slightly larger or smaller component would not change drastically. Scaling of the Geo ICE is shown in Figure-5 so that the ICE gives a maximum power of 50 kW instead of the nominal 43 kW.

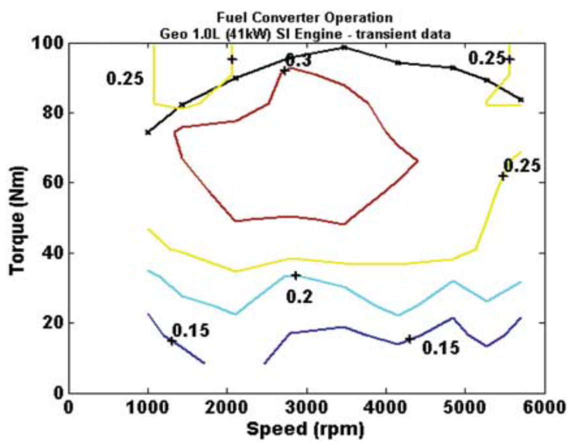

Figure-5. Geo 1.0 L engine scaled to give a maximum power of 50 kW by linear alteration of torque characteristics [3].

In the latest version of ADVISOR, the functionality of the software was improved by allowing links to other software packages such as Ansoft Simplorer [6] and Synopsys Saber [7]. These powerful software packages allow for a more detailed look at the electric systems of the vehicle.

As an application example, ADVISOR is used to simulate a hybrid battery/ultracapacitor energy storage system. More extensive applications can be found in [8], where ADVISOR is used to model hybrid fuel cell/battery powertrain and hybrid fuel cell/ultracapacitor powertrain and simulate their fuel economy and performance. The concept of using a hybrid energy storage system consisting of a battery and an ultra-capacitor (UC) is well known and well documented in literature [9], [10]. The ultracapacitor provides and absorbs the current peaks, while the battery provides the average power required for the electric motor. This arrangement of hybrid energy storage in an HEV extends the life of the battery and allows the motor to operate more aggressively. Simulating such a system in ADVISOR allows the user to visualize the fuel economy benefit. At the same time, the program allows the user to design the best control strategy for the battery/ ultra-capacitor hybrid to improve the battery life and the overall system performance. Finally, the size of the components can be optimized and, thus, the cost and weight of the system can be reduced.

The default battery model in ADVISOR operates by requesting a specific amount of power from the battery as decided by the vehicle control strategy. Depending on the amount of power that the battery is able to supply, the battery module will send out the power available from the battery to the other subsystems. Due to the hybrid backward/forward simulation method of ADVISOR, the amount of power that the batteries are able and required to supply in a given time step is calculated in a single iteration. From this value, the battery model calculates the battery variables like current, voltage, and the battery temperature.

However, a hybrid battery/ultracapacitor energy storage system cannot be modeled within ADVISOR using the above default battery model. So, have to replace the energy storage model with a more complex model. Fortunately, the subsystem model in ADVISOR can be altered as long as the types of inputs and outputs to the rest of the vehicle are not altered. In the simulation, need to replace the battery model by a model of a combination of a battery and an ultra-capacitor connected to a local control strategy unit that splits the power demand between the battery and the ultra-capacitor. Detailed information about the control strategy is available in [9]. The block diagram representation of the system is shown in Figure-6.

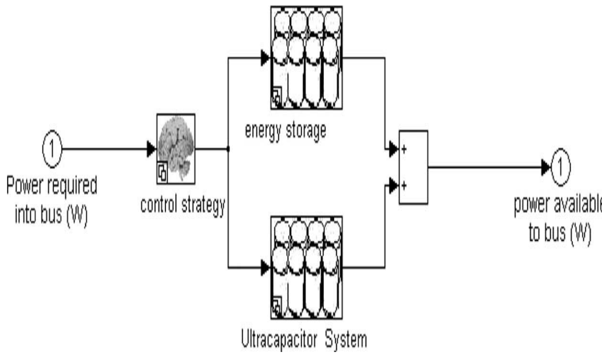

Figure-6. Block diagram representation of new battery subsystem that consists of battery and ultra-capacitor. Input/output relation with rest of the system is left unchanged [3].

The use of the model described gives the user a way to quickly and easily simulate the battery/ultra-capacitor subsystem in a vehicle environment. It allows the user to observe the benefit of using the ultra-capacitor on the fuel economy of the vehicle as well as the benefit to the battery by making the battery state of charge more even and by reducing the peaks of the battery current that the battery has to accept. It also allows the user to validate the system whether it operates as efficiently if the battery size were reduced. Finally, the user can optimize the battery/ultra-capacitor control strategy (in other words, how the power demand will be split) without having to think about the complexities of designing the power electronics to make this control system feasible. In addition, the system can be optimized before any system is built and the system cost and possible savings can be easily calculated at the early design stage. Once the control strategy is optimized, the actual dc/dc converter with the required control strategies can be integrated into the simulation using Saber or Ansoft Simplorer software [9].

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PROPOSED SYSTEM

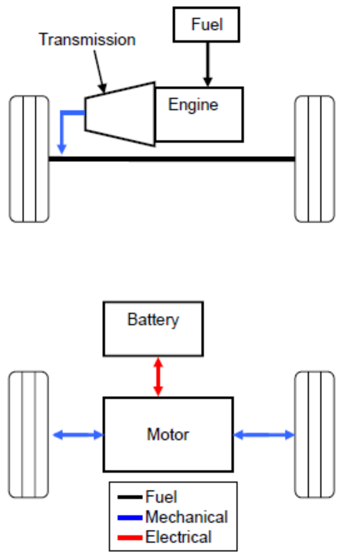

Figure-7. Split plug-in hybrid electric vehicle [2].

The overall objective of this paper is to define a performance for a Split PHEV shown in Figure-7 by simulates powertrain of the system. Figure-8 show block diagram of the system. The results of these simulations should define how the vehicle can decrease fuel consumption, while maintaining low vehicle emissions. Because of the hybrid system, just operating an engine in its regions of high efficiency does not guarantee efficient vehicle operation. These results will not give the specific powertrain commands necessary to enable complete vehicle operation, and are meant only to define a literal strategy; that is, an understanding as to why the vehicle should operate in a certain way under the given conditions.

The system configuration was shown in table-1 below. Small car Produa Kancil was used in this simulation with default component and rear wheel system was installing the 10kW electric vehicle conversion kit.

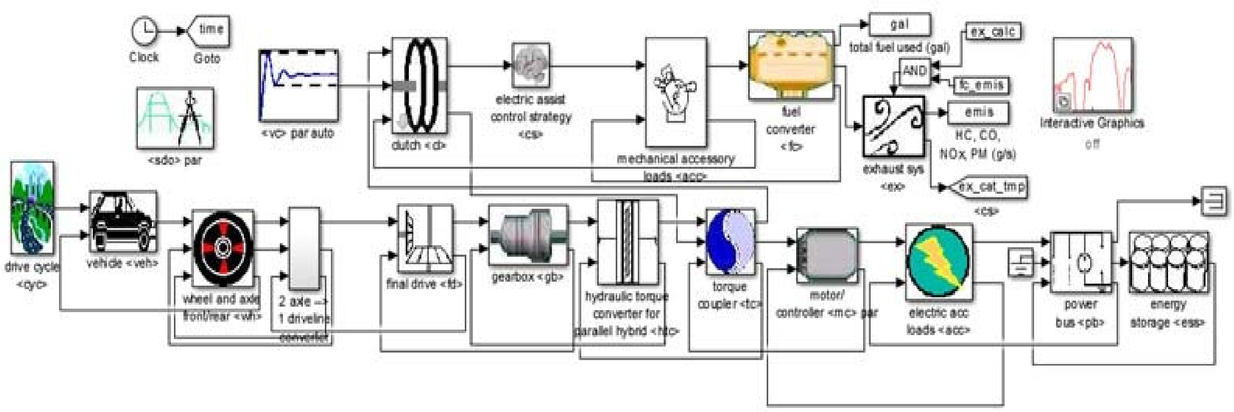

Figure-8. Block diagram of split PHEV in ADVISOR.

Table-1. Split PHEV configuration.

Component	Description
Engine	850CC Gasoline Engine
Motor	10kW AC Motor
Battery	LifePO4 96V 60Ah
Transmission	4 Speed on the front and Rear Axle (Wheel distance 1385mm)Ratio: 10.6:1
Control Strategy	Propelling, Shifting and Breaking
Weight	550kg

Engine operating points are plotted on the Graph of fuel converter operation in Figure-9. Note that the operating points are mostly concentrated in the high efficiency region of the efficiency map. This is the result of using a vehicle control that deploys the mechanical and electrical paths with a view to improve the overall efficiency.

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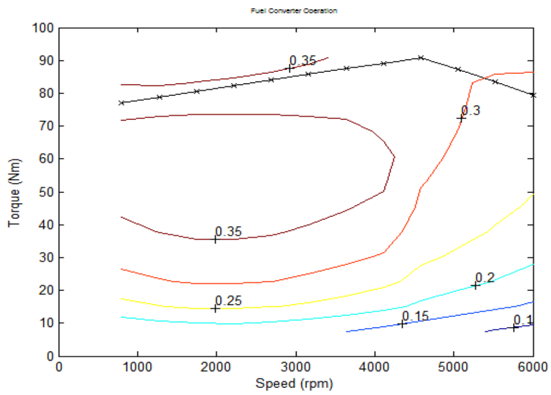

Figure-9. Graph of fuel converter operation.

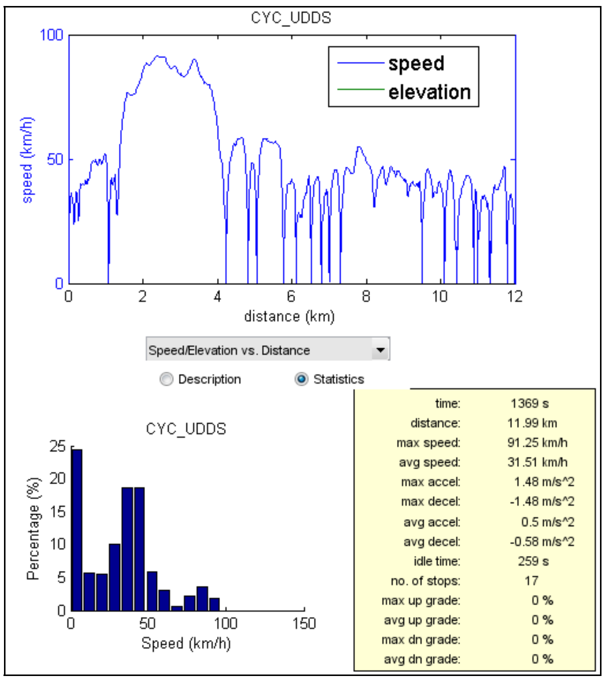

Figure-10. Graph CYC UDDS (Drive Cycle) and performance of split PHEV in ADVISOR.

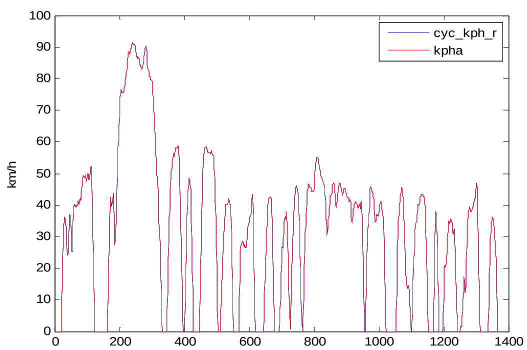

Figure-11. Graph of drive cycle vs speed.

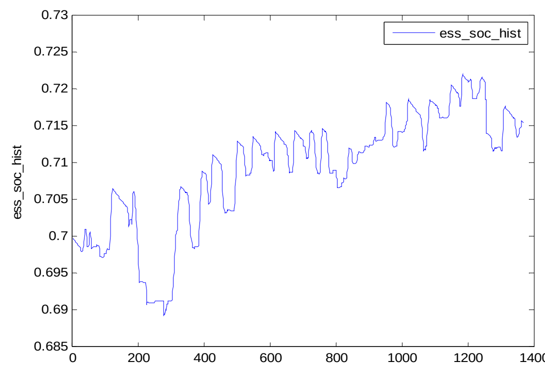

Figure-12. Graph of state of charge (SOC) history.

When the battery state-of-charge is below the desired level, the battery storage must be charged, with charging power coming from the ICE. The ICE power is converted to electrical form in the generator and then stored in the battery. The extra power from the generator is again converted back to mechanical form using the electric motor, and is given to wheels. Figure-12 shows the graph of state of charge (SOC) of the drive-train in this mode of operation.

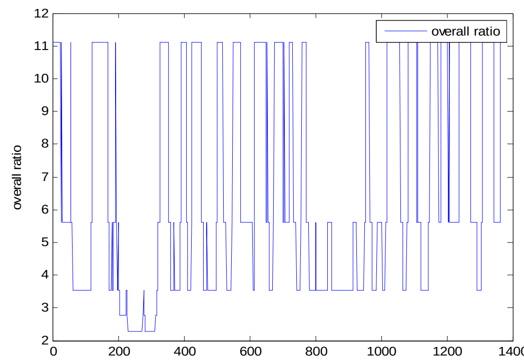

Figure-13. Graph of overall ratio.

The Graphs in Figure-9 till Figure-12 shown the performance of propose split PHEV in ADVISOR. The patent of driving showed in Figure-10 how drive cycle graph perform in speed versus distance. Table-2 show summary result for the propose system. Fuel consumption for this proposes vehicle is approximately 35km/L. The distance for this test is about 12km on city highway road.

Table-2. Result split PHEV.

Fuel Consumption(L/100 km)	2.85
Gasoline Equivalent	2.85
Distance (km)	12

CONCLUSIONS

In this paper, a dynamic model for the split PHEV is developed. This model includes detailed representations for the split hybrid system, the vehicle ICE and electric motor. The developed model is simulated in ADVISOR. Using the proposed vehicle controller, the vehicle can be operated in different modes of operation depending on the driving conditions. The transient response of each mode is also studied in this paper. Using this controller and working in different modes of operation, the engine operates in more efficient areas of the efficiency map which implies a higher efficiency in comparison to the conventional drive-trains.

The developed platform can be used for real-time simulation of the drive-train and also for hardware-in-the-loop simulation of the vehicle if implemented on a real-time simulator such as ADVISOR.

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