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A Review on Modeling and Simulation for Energy Management of Hybrid Vehicles

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ABSTRACT

This paper presents a review of the many simulation tools that have been reported for modeling and managing the energy for Hybrid Electric Vehicle (HEV).In all one hundred and twenty-five simulation tools have been identified by various researchers and among them few tools have been summarized to facilitate selection of the most appropriate tools for specific tasks. Typical applications of the tools include vehicle system analysis and control, renewable energy. No single tool covers all areas of these applications, however different information is provided to enable researchers to select the proper combination of tools to meet precise research objectives.
Key words: EMS, HEV Modeling and Simulation

1. INTRODUCTION

Compared with normal conventional vehicle, more electronic and electrical components are used in electric, hybrid, and fuel cell vehicles. Electric machines, power electronics, electronic continuously variable transmissions (CVT), and embedded are the major component used in next generation power train controllers[1][2]. Advanced energy storage devices and energy converters, such as Li-ion batteries, ultra capacitors, and fuel cells, are introduced in the next generation power trains. The dynamic interactions among various components and the multidisciplinary nature make it difficult to analyze a newly designed hybrid electric vehicle (HEV).Each of the design parameters must be carefully chosen for better fuel economy, enhanced safety, exceptional drivability, and a competitive dynamic performance. Modeling and simulation are crucial for perception evaluation, prototyping, and analysis of HEVs. This is particularly true when novel hybrid power train configurations and controllers are developed. The complex nature of new powertrain designs and dependence on embedded software is a reason of anxiety to automotive research and development efforts. This results in an increasing difficulty in predicting interactions among various vehicle components and systems. A modeling environment that can model not only components but also embedded software, such as the Electronic Throttle Controller (ETC) software, is needed [2]. Effective diagnosis also presents a challenge. Modeling can play an important role in the diagnostic of operating component. A face-off with modeling and simulation tools in the electronics industry has demonstrated that similar tools in the automotive domain still lack the power, sophistication, and automation required by the electronics designers [3]. Advances in electronic design tools have validated Moore's law and have helped achieve amazing standards in computing power while simultaneously decreasing costs. For designers of automotive systems to duplicate and manage similar levels of complexity, design tools that automate the low-level details of the design process need are developed. Depending on the levels of details of how each component is modeled the vehicle model may be categorized as-

- Steady state model
- Quassi state model
- Dynamic state model

Depending on the direction of calculation, vehicle models can be classified as

- Forward looking models
- Backward facing models.

2. SIMULATORS FOR HEV

Khizir [4] presented and summarized a review of sixty-seven simulation tools that have been reported for modeling and managing the impact of electric vehicles on power distribution networks, to facilitate selection of the most appropriate tools for specific tasks. No single tool covers all areas of applications, one has to use different tool to meet specific research objectives. A tool which has been used by many researchers frequently is shown in Table 1. The advantages and limitations of particular tools in each application are summarized.

2.1 HEV MODELING USING PSAT [11]

The Power System Analysis Toolkit (PSAT) is an electric power systems simulation and analysis tool. It is an open-source tool and free to use. The main application of PSAT includes small-signal stability analysis, power-flow analysis, optimal power-flow (OPF) calculation, continuous power flow (CPF) calculation, and time domain simulations. The PSAT program is written in the MATLAB®/ Simulink/Simflow environment to secure more flexibility and modularity (Figure 1)[12]. It supports a variety of dynamic and static power systems model to perform precise power flow analysis. Dynamic model includes fuel cells, wind turbines, synchronous machines, FACTS, regulating transformers, and some non-conventional loads.

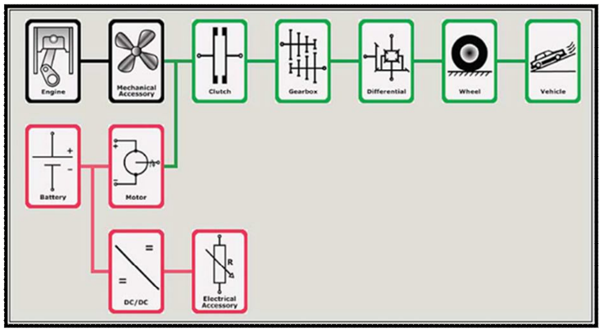

Figure: 1 configuration of hybrid vehicle in PSAT

Table 1 Tools available for modeling and simulations of HEV

Tool	Typical Application	Advantages	Disadvantages
PSAT **[Rousseau et al (2001)]**	Power System Analysis Toolkit	– Power systems, power flow, distributed non conventional load, renewable and user-defined model simulation facility – Compatible with Matlab and Simulink	– Toolbox has potential threat to quality and performance – No vehicle design, V2G, electricity market and planning
Saber **[Liu (2012)]**	Modeling/analysis physical systems, electric power generation/conversion/distribution and optimization	– Design virtual systems, mechatronics systems – Compatible Cadence, Matlab/Simulink, Synopsys VCS, VHDL, Verilog and CAD tools (Pro/E, UGS, Catia V5) – Good to simulate in-vehicle network (Lin, CAN), EV/HEV, power conversion and control	– Cannot simulate all renewable sources, focuses on solar applications only – It simulates the HEV, but doesn't deal with the emission analysis – No vehicle dynamics analysis, no animation
Modelica Toolkit **[Winkler et al (2006)]**	Object oriented multi domain complex system design	– Complex physical systems, mechanical, electrical, electronic systems control – Power systems optimizations including EV, FCV	– Less attention to analyzing distribution system, renewable energy and its integration to grid
DYNA4 Simulation Toolkit **[Francisco et al (2000)]**	Vehicle with energy simulation tools	– Predictive function of battery management, SOC control, EMS of EV, HEV – Advanced vehicle technology simulation including radar, ultrasonic, camera based system –Compatible with Simulink/Matlab	– No V2G, energy economy and emission analysis – Focuses on vehicle dynamics rather than electrical systems
PSCAD/EMTDC **[Anaya et al (2002)]**	Design, analyze and control power systems	–Diversified applications and user-friendly – Perfect to simulate EV, PHEV, V2G, power systems and renewable energy	–Does not focus on all renewable sources or distributed control systems – No EV and grid integration analysis
ANSYS Simplorer **[Hu et al.(2012)]**	Simulate multi-domain systems including electrical power systems, EV and energy market	– Perfect for modeling and analysis of power transmission and distribution systems, grid monitoring and optimization – Integrate distributed generation, analyze its impact on grid	– No EV design, dynamics analysis – Environmental factors are neglected in simulations – Not free to use
ADVISOR **[Wipke et al (1999)]**	Virtual vehicle analysis	– Fuel economy and emission analysis – Different types of vehicle	– For vehicle analysis, not design – Quasi-static component

2.2 HEV MODELING USING SABER [11]

Saber is a simulation tool for simulating, modeling, designing and optimizing physical systems, power electronics, mechatronics systems and electric power generation and conversion and distribution. It has implemented several projects in industrial power and energy systems, aerospace and automotive sectors. It is a commercial tool (demonstration version and student version free to use) developed by Synopsys. It has a Windows-based IDE and is easy to use, with good novice accessibility. The main goal with this tool is to visualize mechatronic and electronic systems and optimize performance and reliability, accelerate the electrification process of industrial, aerospace and automotive systems, enhance hardware quality by reducing prototyping iterations, integrate physical systems with electronics and software design [6].Saber consists of various application solutions: Saber Automotive Applications Solutions deals with HEV Powertrain, EV and HEV design, analysis and optimization; Saber Aerospace Applications Solutions deals with avionics networks, power conversion and power networks, flight-control systems design, analysis, and optimization [12] Saber Solar Applications Solutions deals with power electronics, power distribution networks and PV tracking & Control Systems design, analysis and control [11].

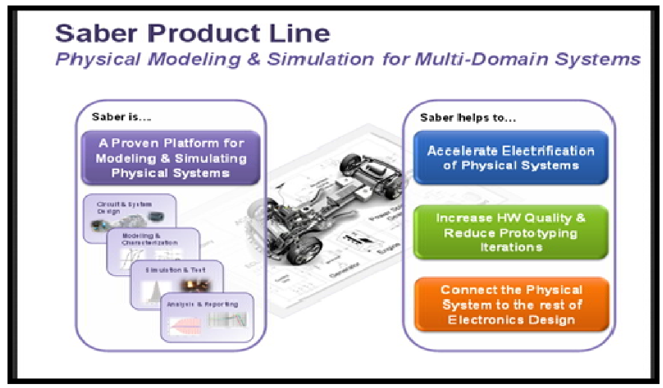

Figure 2 Physical modeling & simulation in Saber (www.synopsys.com/saber)

2.3. HEV MODELING USING MODELICA [Fritzson et al (2011)]

Modelica is an object-oriented multi-domain complex system design tool [17]. It is maintained by the Modelica Association and is free to use. The Modelica Association is a non-profit organization, its wide range of members is from Canada, U.S.A., Asia and Europe, and its experts are working to develop Modelica standard library functions. A significant number of research groups and institutions are using this tool. Many automotive companies like VW, BMW, Toyota, Ford, and Daimler are using this tool to design energy-efficient vehicles. Some power-plant provider companies like ABB, Siemens, EDF are also using Modelica for energy systems research. Its applications are broadly categorized into several sectors such as electrical, electronics, mechanical, hydraulics, thermal, process-oriented subcomponents, electric power, and control [18] Modelica facilitates a large number of models and library components. It has 1280 model components with 910 functions. It consists of a large number of simulation environments such as Wolfram SystemModeler, CATIA Systems, SCICOS, JModelica.org, Dymola, Vertex, CyModelica, OpenModelica, MapleSim, SimulationX, and LMS AMESim. The Modelica simulation tool is compatible with MATLAB/Simulink, and by using SimulationX, MapleSim, Dymola, and Vertex Modelica models are imported into Simulink .It can simulate analog electric and electronic components, digital electric components, electrical machines, limped magnetic networks, controlled electrical machines [19], mechanical translation systems, aircraft[20], vehicle dynamics, vehicle powertrain [21], vehicle to grid integration, power generation, and power systems.

2.4 HEV MODELING USING DYNA4 [Francisco et al (2000)]

The DYNA4 Simulation Toolkit consists of several tools (veDYNA, DYNA4 advanced powertrain, DYNA4 Car Professional, DYNA4 Commercial Vehicles, DYNA4 Framework, DYNA4 Engine Professional, etc.) to analyze and design various types of vehicle. It is a commercial tool, not free to use, developed by TESIS, DYNAware. DYNA4 is compatible with MATLAB/Simulink and uses its environment to analyze and develop vehicle powertrain and control systems. It allows users to integrate Simulink models with DYNA4's real-time model library for increased flexibility. The DYNA4 simulation tool named DYNA4 Elements provides an environment to load a user's model for a wide range of applications including vehicle drivetrain, dynamics, hydraulics, etc. An additional toolbox provides an environment for traffic analysis. The hybrid toolbox of this software deals with distance control, virtual traffic environment, vehicle dynamics analysis, topology analysis for battery electric and hybrid electric vehicles, battery management, predictive battery SOC management, engine start and stop function, thermal management, regenerative braking, torque coordination, optimized operation strategy, fuel economy, and efficiency enhancement. It can also generate animations of the simulated vehicles. Figure 3 shows the extended support can be used in DYNA4

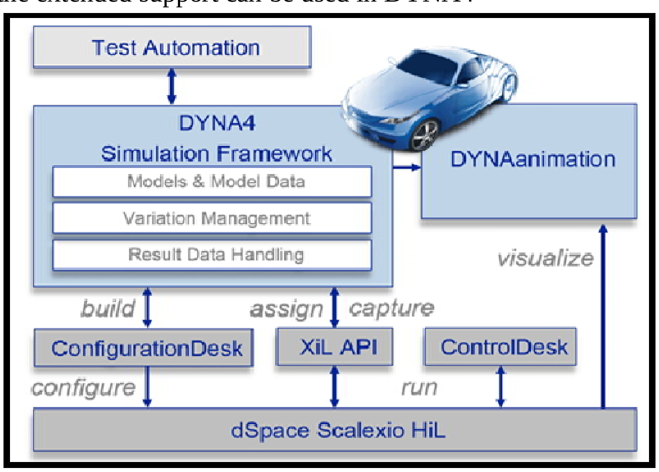

Figure: 3 Physical modeling & simulation in DYNA4(http://www.tesis-dynaware.com)

2.5 HEV MODELING USING SIMPLORER AND V-ELPH [22]

Simplorer is a multi domain simulation package that can be used for system-level HEV modeling. It has a comprehensive automotive component library, including batteries, fuel cells, and wires, fuses, lamps, electrical motors, alternators, and engine models, relays, in addition to the electronics, power electronics, and controller models. This capability provides even greater modeling and simulation accuracy for automotive electronics and machine design. A series hybrid electric vehicle is modeled in Simplorer. V-Elph is a system level Matlab® /Simulink® -based modeling, simulation, and analysis tool. This package uses detailed dynamic models of electric motors, internal combustion engines, batteries, and vehicle. The dynamic performance and fuel economy, energy efficiency, emissions, etc., can be predicted for hybrid and electric vehicles. In addition, software packages, such as Modelica, and Saber are also used in the physics-based modeling and simulation of hybrid and electric vehicles.

2.6 PHYSICS BASED MODELING [23]

PSAT and ADVISOR are based on experiential models in the form of look-up tables and efficiency maps. The accuracy of these tools may not be good enough for vehicles operating under extreme conditions. For detailed dynamic modeling and simulation of HEV system, physics-based modeling is needed. VTB, PSIM, Simplorer, V-Elph are good examples of physics-based modeling tools, where the state variables of a component or subsystem are modeled according to the physical laws representing the underlying principles. The resulting model is a function of device parameters, physical constants, and variables. Such physics-based models can facilitate high fidelity simulations for dynamics at different time scales and also controller development. RCF modeling technique comes under physics based modeling. The RCF method originates from electrical engineering but is suitable for multidisciplinary modeling applications such as hybrid powertrain. The RCF method has been used successfully in a number of industry-standard electronic design tools such as SPICE and Saber. Recently, it has also been applied in the Virtual Test Bed, which is being recognized as the leading software for prototyping of large-scale multi technical dynamic systems

2.7 BOND GRAPH MODELING TECHNIQUE FOR HEV [24]

Bond graphs are a graphical tool used to describe and model subsystem interactions involving power exchange. The bond graph has been proven effective for the modeling and simulation of multi domain systems including automotive systems .In a Bond Graph model, a physical system is represented by basic passive elements that are able to interchange power: resistances (R), capacitances (C), and inertias (I). Although these names suggest a direct application in electrical systems, they are used in any other domains as well, e.g., friction as a mechanical resistance, a compressible fluid as a capacitance, and a flywheel as an inertial element. Each element has one or more ports where power exchange can occur. This power (P) is expressed as a product of two variables: effort (e) and flow (f). These names are used extensively in all domains but have a unique name on each domain: force and speed in mechanical, voltage and current in electrical, pressure and flow in hydraulics, and so on. Additional variables are defined: momentum (p) as the time integral of effort and displacement (q) as the time integral of flow.

Additional elements are needed to fully describe a system: sources of effort (Se) and sources of flow (Sf) are active elements that provide the system with effort and flow respectively; transformers (TF) and gyrators (GY) are two-port elements that transmit power, but scale their effort and flow variables by its modulus; and one junction (1) elements are multiport elements that distribute power sharing equal flow, while zero junction (0) elements distribute power, having equal effort among all ports. Bond graph elements are linked with half arrows (bonds) that represent power exchange between them. The direction of the arrow indicates the direction of power flow when both effort and flow are positive. Full arrows are used when a parameter is to be passed between elements, but no power flow occurs. A bond graph can be generated from the physical structure of the system. For example, the HEV powertrain connected to a road load model can be drawn as shown in Figure 4.

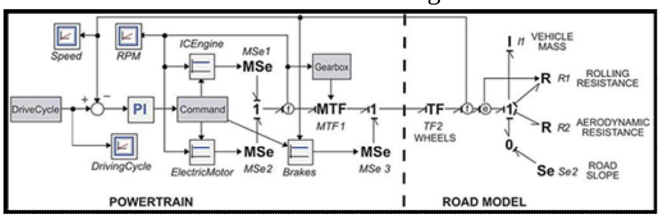

Figure 4 HEV Power train model connected to road model

2.8 HEV MODELING USING ADVISOR

Advanced vehicle simulator (ADVISOR) is a virtual vehicle analysis tool which uses the MATLAB environment and Simulink components. It is a free tool, developed by NREL [25]. The tool has been developed to evaluate fuel economy and vehicle performance for all types of vehicles (conventional, hybrid and electric vehicle). It can estimate the fuel economy of vehicles with future technology. It uses a user-defined drivetrain and can compare the energy usage and loss of conventional hybrid, and electric vehicle drivetrain, and can also compare relative tailpipe emissions. It can evaluate an energy management strategy for a certain fuel converter and can suggest how to optimize fuel usage to maximize performance. ADVISOR was initially developed in 1994 to manage USA DOE hybrid vehicle propulsion systems. Since its development thousands of individuals, and several industries and universities, have used this tool [22]. However, ADVISOR has a few limitations. It was developed as a vehicle analysis (not design) tool. It uses component models which are quasi-static and fail to predict phenomena on less than a 0.1 s timescale. The simulation deals in power, not voltage or current level, but can work with a voltage bus when linked to other tools like Simplorer or Saber [12]It is a very user-friendly tool with good graphical representation. MATLAB/Simulink must be installed to run this tool. Fig. 5 shows the modeling of parallel HEV done in ADVISOR.

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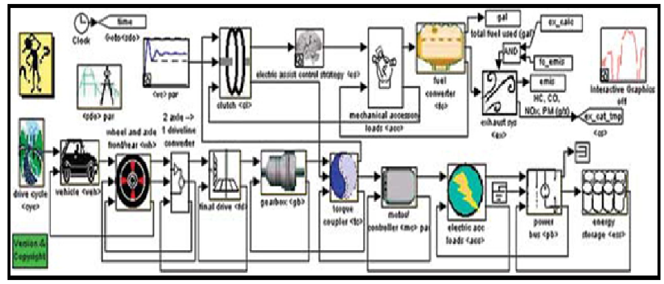

Figure 5 Block Diagram of Parallel HEV in ADVISOR

3. CONCLUSION

This paper has presented an overview of the modeling and simulation of HEV.HEV being a multidisciplinary system its modeling using a single platform is desirable.wide range of simulation tools is available to design and analyze systems with various types of vehicle, traffic system, and their integration with the power distribution grid. Each tool is specialized to simulate specific systems. For vehicle modeling and analysis, FASTSim, ADVANCE, DYNA4 Simulation Toolkit, V2G-Sim, , CASPOC, HYPERSIM/ ePOWERgrid, Modelica Toolkit and Saber simulation tools are appropriate. The ADVISOR tool is appropriate for vehicle analysis, especially for emission analysis. No single tool can perform the entire task so depending on requirement researchers have to use the specific one.

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