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Multi-Physic Modeling and Simulation of a Hybrid Vehicle with Range Extender

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Abstract

As the global economy begins to strain under the pressure of raising petroleum prices and environmental concerns, automobile manufacturers constantly strive to produce more fuel efficient and environmentally friendly vehicles. That's why mechatronic sophistication in automotive vehicles is increasing. Given the current resources and technologies, the most feasible solution is hybrid electric vehicles (HEV). HEVs can be organized into three classes: parallel, series and power-split hybrids.

In an electric car with a Range Extender, only the electric motor drives the wheels. It is powered by a battery for a few tens of kilometers. Then when the battery reaches a level load of about 30%, a thermal engine optimized, which drives a current generator, starts producing electricity for the onward journey.

In this paper, we focused on the series hybrid architecture. We analyzed different architectures and more precisely the hybrid solar vehicle with Range Extender. We developed a dynamic model of this multidisciplinary system and its control unites using software of multi-physics modeling. The simulation results were used for an operating cycle NEDC (New European Driving Cycle) to optimize fuel consumption.

Keywords: Hybrid vehicle, Range Extender, Multi-physique modeling, solar Hybrid.

Introduction

The concern about pollution, petroleum stockroom and its price as well as global warming leads to the development of electric vehicles. At the beginning of the last century, engineers try to reduce the fuel consumption by adapting electric drive, being known that CO2 gas emission, which has the most important contribution in greenhouse effect, is directly proportional with engine fuel consumption. However, many producers from automotive industry today offer hybrid electric models. The idea is to combine two different energy sources to maximize vehicle performance (increase the efficiency of the drive train). Hybrid electric vehicle architectures are organized into three classes: Parallel, Series and power split hybrids. In this article we will be interested in hybrid series with Range Extender.

Thus, in this work, we study different characteristics of this vehicle's configuration and we propose a model of a Solar Hybrid Vehicle with Range Extender under a multi-physics modeling software. We finally present the simulation results of the operating cycle NEDC in order to reduce consumption.

Description of Solar Hybrid Vehicle with Range Extender

Hybrid vehicle

A hybrid vehicle is a vehicle in which are incorporated two different energy sources. Typically a combustion engine and an electric motor. The most common hybrid vehicles are hybrid electric vehicles (HEV) involving conventional internal combustion engine (ICE) propulsion system and an electric propulsion system [1].

HEV architectures are organized into three classes:

- <u>Series hybrid</u>

In a series HEV, the vehicle is propelled solely by the electric motor. The electric motor obtains the required energy from either a battery, or a motor-generator set. The motor-generator set supplies power to the electric motor and an energy storage device (i.e. a battery or super capacitor). The purpose of the energy storage device is to allow more power to be drawn by the electric motor during more demanding driving conditions (hill climbing, hard accelerations, etc.)[9]. The Figure1 shows series hybrid architectures.

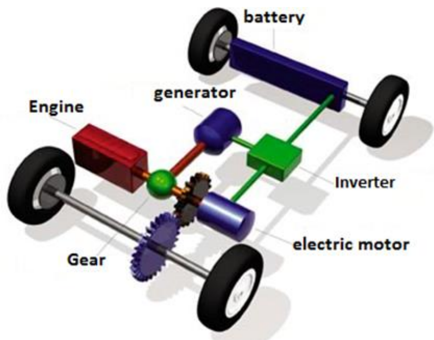

Figure1: Series hybrid vehicle

The advantage of this architecture is that the engine operates at a high efficiency which reduces the level of pollutant emissions. The main drawback is the energy loss in the drive line.

- Parallel hybrid

In the parallel architecture, the internal combustion engine and the electric motor provide the torque to the wheels. The battery in this time is only recharged by the electric motor in generator operation mode. As shown in Figure 2 the power supplied from both sources circulates in parallel [2].

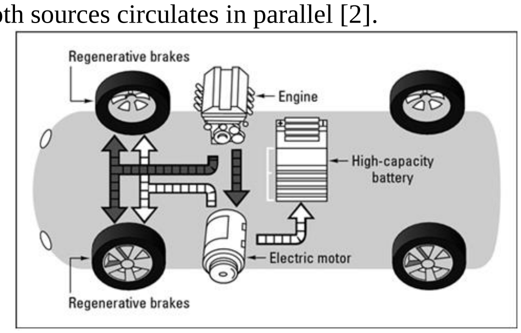

Figure 2: Parallel hybrid vehicle

The advantage of this architecture is that the loss of energy in the driveline is minimum.

- Power split hybrid

The third architecture in Figure 3 is the power split hybrid (series / parallel), which is a combination of the other two architectures in order to benefit from advantages of both systems. Two electric motors and combustion engines are used [3].

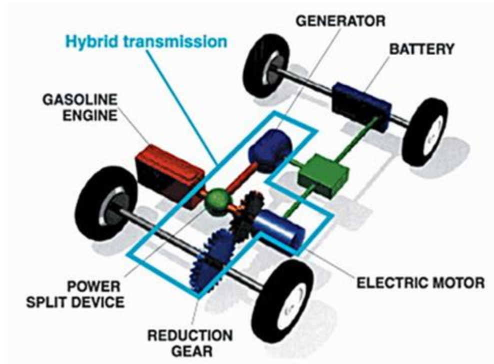

Figure 3: Power split vehicle

This configuration offers multiple solutions to provide power to the wheels or charge the battery, allowing the use of different engines in their areas of high performance according to the current operation mode.

Hybrid vehicle with Range Extender

The hybrid vehicle with Range Extender shown in Figure 4 is a kind of hybrid series architecture with a similar use of electric vehicles. It is distinguished by an ability to operate out of the battery ranges. For that, it is fitted with a large battery and a small engine.

Depending on the option selected, the engine can provi de power for the vehicle to continue to operate when the battery is low, but with a reduced level of maximum power: the vehicle, in this case, is used mainly as an electric vehicle. Another solution is to provide the average power required to operate the vehicle by the engine and the complement of the power required by the battery. The vehicle in this case operates in a hybrid mode.

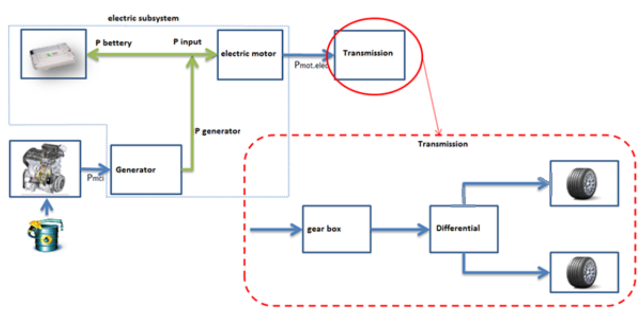

Figure 4: Architecture of HEV with Range Extender

Solar vehicle

Solar energy is a renewable source of energy. In recent years, several countries adopted photovoltaic in order to reduce the role of fossil fuels in our

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lifestyle. This concept is also used in automotive industry. Although the energy provided by a cell remains relatively low, it can be used to power auxiliary organs of a vehicle [4].Solar cars combine technology generally used in aerospace, bicycle, alternative energy and automotive engineering. The design of the solar vehicle is particularly limited because of the amount of energy required by the vehicle. Most solar vehicles are built in order to participate in solar car races [5].

Solar panels produced energy that provides propulsion of the vehicle. Before going towards the organs to serve, this energy passes through batteries. Batteries compensate the missing energy if the panels do not provide enough energy. Solar vehicles must operate so that the energy amount required is equal to that produced by the panels to assume greater autonomy.

Modeling and Simulation of the System

Environmental modeling description

To implement a blocks diagrams model of the vehicle, we use AMESim (Advanced Modeling Environment for performing simulations) of LMS International, which is a dynamic simulation environment of various engineering fields: mechanical, electrical, thermal systems and also physical multidomain systems [6]. Indeed, the models of components of these fields can be combined harmoniously in an easy to use interface. AMESim's multi-port modeling of physical components as well as its block-diagram approach for control systems enables the coupling of all its libraries together, within a built-in and comprehensive workflow [7].

Each block is equipped with input and output ports of energy. These sub-models are defined by the geometrical and physical parameters. Causality is enforced by connecting the inputs of a sub-model to the output of another sub-model. The sub-models interconnection allows the development of 1D model of a real system or an under designed system. The software automatically constructs equations characterizing the system's behavior and allows simulating and analyzing the parameters of the physical system [8].

Physical model of control unit

The control unit allows providing the necessary torque to meet the driver request. When the vehicle speed is less than that requested by the driver the vehicle accelerates and brake in the opposite case. The acceleration has a coefficient of 0 to 1. Figure 5 shows the model used of the control unit.

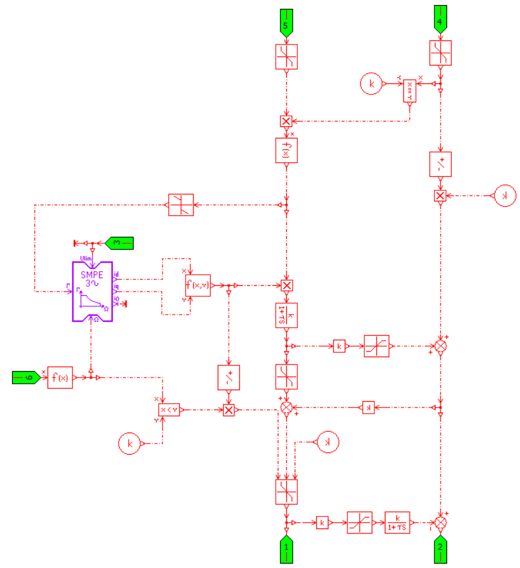

Figure 5: AMESim model of the control unit

Physical model of the solar panel

A solar panel is a set of solar photovoltaic modules electrically connected and mounted on a supporting structure. A photovoltaic module is a packaged, connected assembly of solar cells which model is shown in Figure 6:

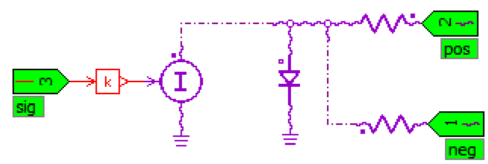

Figure 6: Model of photovoltaic cell

Each module is rated by its DC output power under standard test conditions (STC), and typically ranges from 100 to 320 watts. The efficiency of a module determines the area of a module given the same rated output - an 8% efficient 230 watt module will have twice the area of a 16% efficient 230 watt module. A single solar module can produce only a limited amount of power; most installations contain multiple modules. A photovoltaic system typically includes a panel or an array of solar modules, an inverter, and sometimes a battery and/or solar tracker and interconnection wiring.

The solar panel used in this case is formed by two parallel panels as shown in Figure 7 in order to have a high current.

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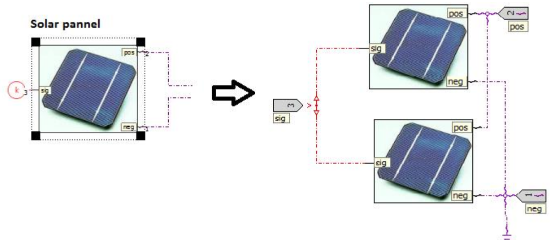

Figure 7: Model of the solar panel

Physical model of the electric motor

Electric motors in the dynamic mode present nonlinearities. For that reason we apply the Park transform which used to convert voltages and currents for each coil in the repository a, b, c into two components in the repository d, q, 0 [9].

Using this transform, we could model the control circuit of the electric motor given in Figure 8:

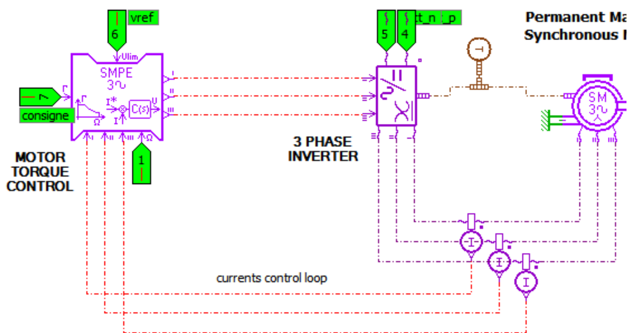

Figure 8: Model of the control circuit of the electric motor

Physical model of the Range Extender

We modeled the range extender unit so that it turns on when the battery drops to a lowest level and stops working when the batteries are charged. Its model is given in Figure 9:

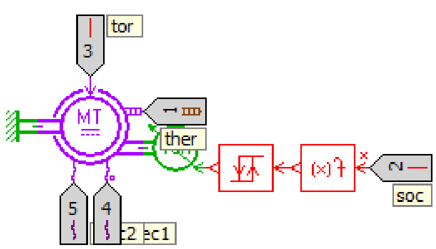

Figure 9: Model of the Range Extender

Simulation model

The interconnection of models which represent the system allows the assemblyof the complete model of solar hybrid vehicle shown on Figure 10.

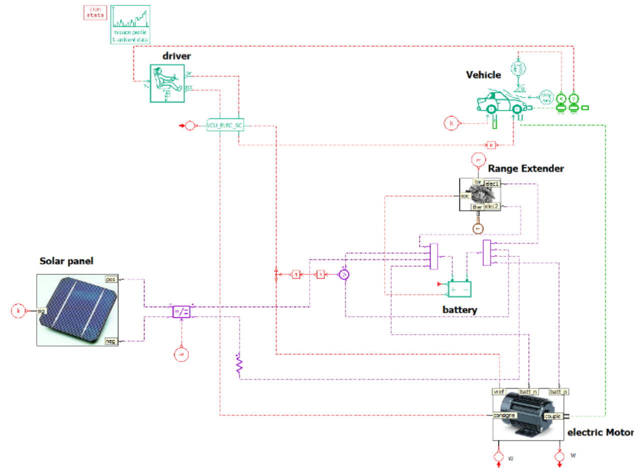

Figure 10: Complete model of solar hybrid vehicle

The simulation results

The modeling approach under LMS AMESim environment makes it possible to simulate the input and output variables of various components. We can visualize the evolution curves of these variables with time and compare them with those of the actual model. For example, In Figure 11 and Figure 12, we can see that the profile of the vehicle speed and the torque are almost the same as those of setpoints representing speed and torque given in the NEDC cycle which lasts 1,200 seconds.

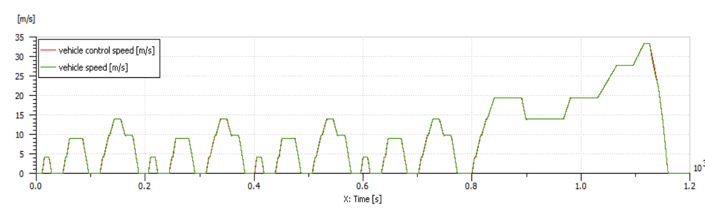

Figure 11: Profile of the vehicle speed and speed setpoint

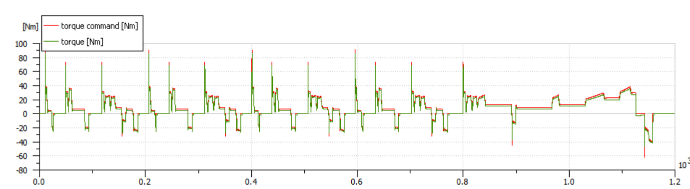

Figure 12: Torque profile and torque setpoint

During the operation time of the vehicle, the battery provides power till a level where it discharges as in Figure 13 and the Range Extender starts to reload it again. The range extender unit is activated when the battery level drops below 76%.

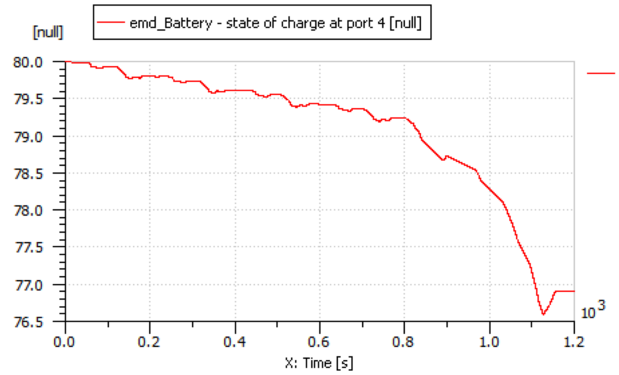

Figure 13: load level of the battery

The diagram in Figure 14 shows the area of the maximum yield of the Range Extender.

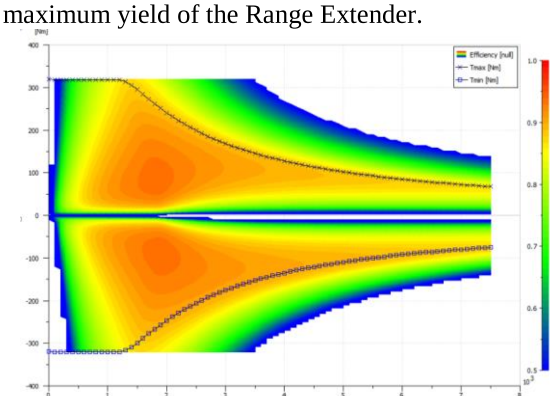

Figure 14: Unit range extender response

This zone is presented in red corresponding to a rotational speed of 1500 rpm and a torque of 63Nm. We can see that at this point the yield is 90%.

Conclusion

In this work, we analyzed different hybrid architectures that exist showing the strengths and weaknesses of each one. We conducted a physical study and identification of operating characteristics of each component of the solar hybrid vehicle with Range Extender. Then we developed a physical model of this system using a multiphysic modeling and simulation tool.

In addition, the interconnection of these components gave us the ability to simulate and analyze the vehicle parameters and the simulation allowed us to validate its dynamic parameters and compare with those of the NEDC cycle.

We found that the energy extension or range extender, coupled with a solar energy source, can significantly reduce the weight of the batteries and increase the vehicle's range.

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