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MODEL ANALYSIS FOR HARDWARE IN THE LOOP SIMULATION APPLIED IN HYBRID ELECTRIC VEHICLES

BY

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Abstract. The present paper introduces a new integrated method for an energy performance analysis of the hybrid electric vehicles. This method takes into consideration the acceleration and deceleration factors that influence the energy efficiency. The research is based on Matlab modeling and Hardware in the Loop approach. The added value is given by the accuracy of the model that is part of the simulation together with the presented performance analysis methods. A set of 10 case studies are proposed and the efficiency of the method is demonstrated through a series of simulation results. The motivation of the research is given by the fact that the actual fleet of hybrid electric vehicles faces many challenges regarding the driving range which makes the energy efficient operation critical. The advantage of this method is that the systems performance can be validated to a large extent from an early stage. The results can contribute to the practical need of developing hybrid and electric vehicles with a higher energy efficiency and with lower costs.

Key words: hybrid electric vehicle; HIL; simulation; modeling.

1. Introduction

The research in the domain of Hybrid Electric Vehicles (HEV) has concentrated in the latest years in finding solutions for efficient motors and engines, reduced fuel emissions and better battery lifetime. In the last years, the

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share of software controlled innovations in the automotive industry increased from 20% to 80%. This is continuously growing and it is estimated that software will drive more than 90% of the automotive systems in the next years. Considering this, the impact of software in electric vehicles will be very high. In order to have good achievements in the testing process, the test environment needs to be very realistic. In the last years the automotive industry is driven to more complex electronic control systems. In the same time, mathematical modeling and simulation tools became more advanced and the concept of simulation became an actual design tool. Simulation is now the primary tool used before real world testing is possible.

This paper presents a set of case studies based on simulations and a new method of performance analysis. In section **2**, a set of 10 case studies together with simulation results and data analysis are presented. Ten driving cycles are analyzed in order to evaluate the impact of the acceleration and deceleration coefficients on the vehicle energy efficiency. The simulations results are assessed with the purpose of creating a performance matrix. In section **3**, a set of conclusions together with the direction of further research are presented. The goal is to improve the energy efficiency of hybrid and electric vehicles.

2. Case Study (Matlab model for HIL) – Analysis

The block diagram of the model used in the performance analysis method is presented in Fig. 1.

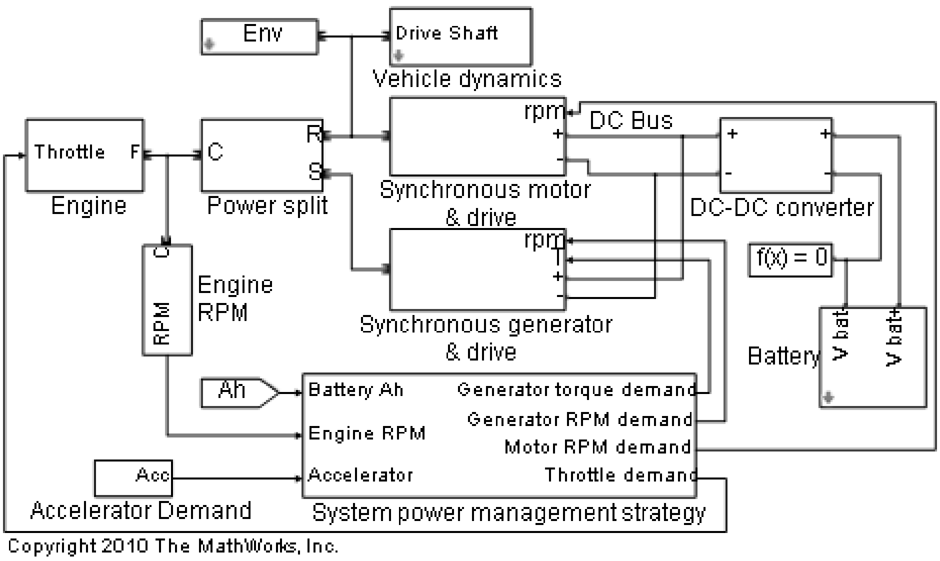

Fig. 1 – Model Block Diagram.

The model has several parameters that can be configured, but the analysis is concentrated on the impact of the acceleration and breaking factor to the DC current, DC voltage, Generator Power and Battery Power. On a defined driving cycle profile several acceleration and deceleration gradients are defined and their impact analyzed in order to generate a new type of performance matrix. The profile of the driving cycle defined in this paper has several accelerations and decelerations over a short period of time. This type of driving style was analyzed in one of my previous research and the best energy efficiency was obtained with a vehicle mass of 600 Kg, an internal combustion engine of 53kW and a battery voltage of 200 V. Considering this configuration several acceleration and deceleration gradients are modeled in this paper under the same driving cycle profile. A set of 10 case studies are defined as presented in Table 1. The study focuses on a driving profile with an acceleration from 0 to 45 km/h performed between 5 and 15 s, followed by a deceleration to 10 km/h performed between 5 and 15 s, again an acceleration to 32 km/h in the same time range, and a last braking profile in the same time window until 6 km/h.

The Accelerator (Acc) in Table 1 is converted to engine speed demand. A pedal deflection of 0.1 corresponds to 20 km/h that results in the speed demand of 800 rpm. Full accelerator corresponds to 2,500 rpm which in turn is equivalent to 200 km/h. Acc is defined to vary between 0 and 1.

Table 1
Driving Cycles Definition

DC												
1	T[s]	0	5	15	30	44	50	55	70	84	87	90
	Acc	0	0.2	0.2	0.2	0.05	0.05	0.15	0.15	0.03	0.03	0
2	T[s]	0	6	16	30	43	50	56	70	83	87	90
	Acc	0	0.2	0.2	0.2	0.05	0.05	0.15	0.15	0.03	0.03	0
3	T[s]	0	7	17	30	42	50	57	70	82	87	90
	Acc	0	0.2	0.2	0.2	0.05	0.05	0.15	0.15	0.03	0.03	0
4	T[s]	0	8	18	30	41	50	58	70	81	87	90
	Acc	0	0.2	0.2	0.2	0.05	0.05	0.15	0.15	0.03	0.03	0
5	T[s]	0	9	19	30	40	50	59	70	80	87	90
	Acc	0	0.2	0.2	0.2	0.05	0.05	0.15	0.15	0.03	0.03	0
6	T[s]	0	10	20	30	39	50	60	70	79	87	90
	Acc	0	0.2	0.2	0.2	0.05	0.05	0.15	0.15	0.03	0.03	0
7	T[s]	0	11	21	30	38	50	61	70	78	87	90
	Acc	0	0.2	0.2	0.2	0.05	0.05	0.15	0.15	0.03	0.03	0
8	T[s]	0	12	22	30	37	50	62	70	77	87	90
	Acc	0	0.2	0.2	0.2	0.05	0.05	0.15	0.15	0.03	0.03	0
9	T[s]	0	13	23	30	36	50	63	70	76	87	90
	Acc	0	0.2	0.2	0.2	0.05	0.05	0.15	0.15	0.03	0.03	0
10	T[s]	0	14	24	30	35	50	64	70	75	87	90
	Acc	0	0.2	0.2	0.2	0.05	0.05	0.15	0.15	0.03	0.03	0

The vehicle speed representation for all 10 case studies is presented in Fig. 2. All driving cycles are overlapped in the same figure for a better overview. It can be observed that the end speed value is the same on all driving cycles but this value is reached in different time periods. These different time windows represent the acceleration and deceleration gradients under study. This new method of analysis assesses the impact of these factors or gradients on the energy efficiency.

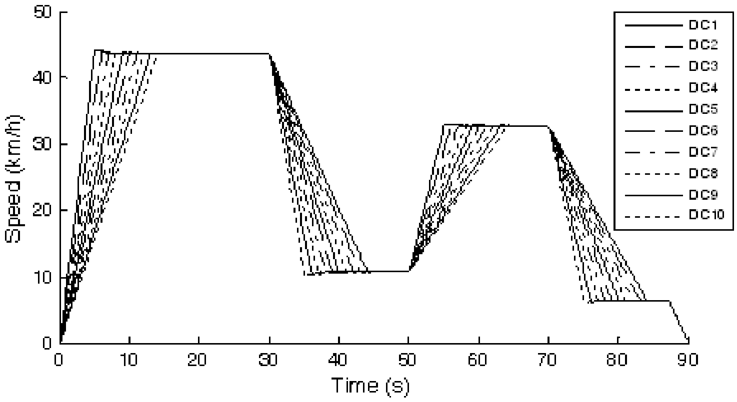

Fig. 2 – Vehicle Speed for all driving cycles under analysis.

The paper underlines the fact that any small change in the acceleration or deceleration factor has a direct impact on the Battery Power, on the DCbus voltage, DCbus current and other parameters that contribute to the vehicle energy efficiency. The performance in motor mode or generator mode is also influenced by the above mentioned factors. A good understanding of this impact contributes to a better energy management in the hybrid vehicle control system.

On the simulation model several accuracy improvements were performed. The charge level is tracked, and a simulation error issued if it either exceeds the ampere-hour capacity, or falls below 10% of the ampere-hour capacity. The Internal Combustion Engine (ICE) that is part of the analyzed hybrid architecture is modeled as a simple gasoline fuel engine model with speed governor. The throttle input signal lies between zero and one, and specifies the torque demanded from the engine as a fraction of the maximum possible torque. This signal also indirectly controls the engine speed.

The impact of the 10 performed case studies on the DCbus voltage and DCbus current is presented in Fig. 3.

This newly proposed integrated method for performance analysis assesses the impact of the acceleration and deceleration factors and contributes to the practical need of developing more energy efficient hybrid electric vehicles. The method is intended to help the drivers of these vehicles to save energy and in this way increases the driving range. It is established that there is a close connection between vehicle energy efficiency and the performance of the generator in a hybrid vehicle. The profile of the generator power obtained from the simulation method is presented in Fig 4. Each driving cycle with the corresponding acceleration and deceleration factor has its own unique contribution to the generator power profile. This impact shows the importance of identifying the best parameterization trough the analysis method defined in this paper.

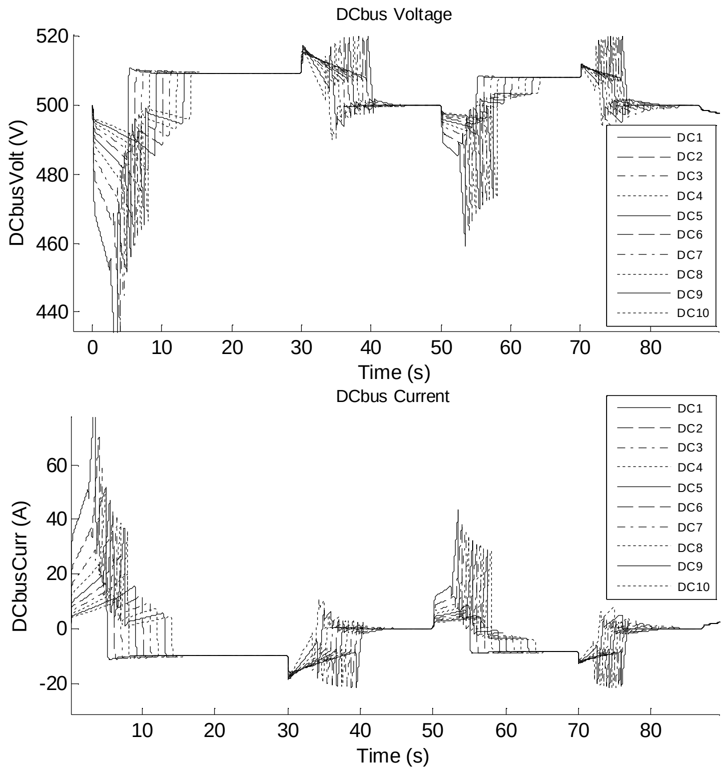

Fig. 3 – DCbus voltage and DCbus current for all driving cycles under analysis.

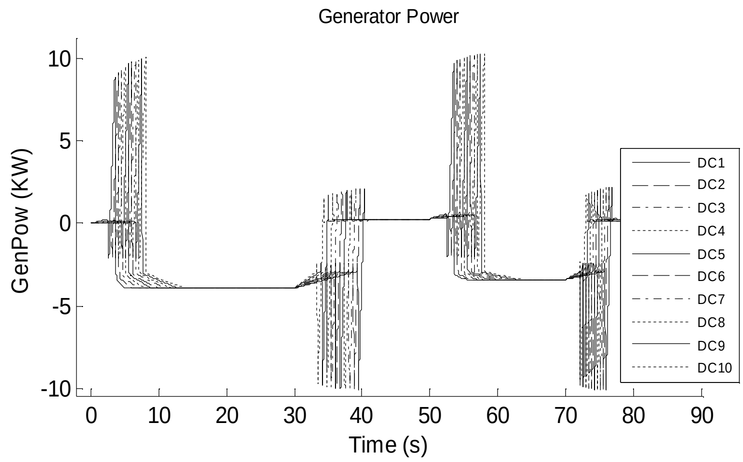

Fig. 4 – Generator power for all driving cycles under analysis.

Recorded data from all 10 proposed test scenarios is considered in the research. Data analysis shows that the battery charge time percentage varies between 38.5645% and 70.1905% over all test scenarios. The discharge time percentage varies between 29.8095% and 61.4355% over all test scenarios. The most efficient combination of acceleration and deceleration factors is given by the first driving cycle (DC1). The analysis is also extended to asses the activation and deactivation of the generator mode. Additional data analysis shows that the generator mode activation time percentage varies between 46.2197% and 67.0018% over all test scenarios. The generator mode deactivation time percentage varies between 32.9982% and 53.7803% over all test scenarios. The most efficient combination of acceleration and deceleration factors with impact on the generator behavior is given by the first driving cycle (DC1).

A graphical representation of the results presented above is presented in Fig. 5. These results underline the fact that the acceleration and deceleration factor have a high impact in driving cycles where many acceleration and breakings are performed. This leads to the conclusion that in this type of driving cycle most efficient for the energy saving while driving a hybrid vehicle is to accelerate fast and break slow.

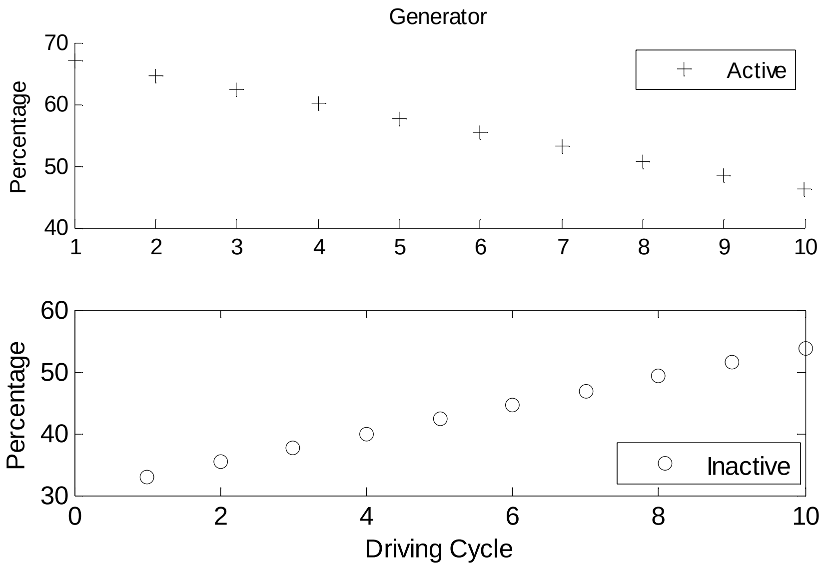

Fig. 5 – Impact of driving cycles on the generator energy efficiency

The results from the test scenarios presented in Fig. 5 show a linear dependency between the acceleration and deceleration factors and the impact on the generator power and furthermore on the energy efficiency. The most efficient scenario is the first one (DC1) detailed in Table 1. For a better understanding of the Power distribution a 3D representation of the drive cycle corresponding to test scenario number 1 is shown in Fig. 6. The graph covers only the first acceleration and deceleration for a better overview. One can notice how the energy is lost during acceleration and recovered during the deceleration phase. The challenge always remains to equilibrate and make this balance positive.

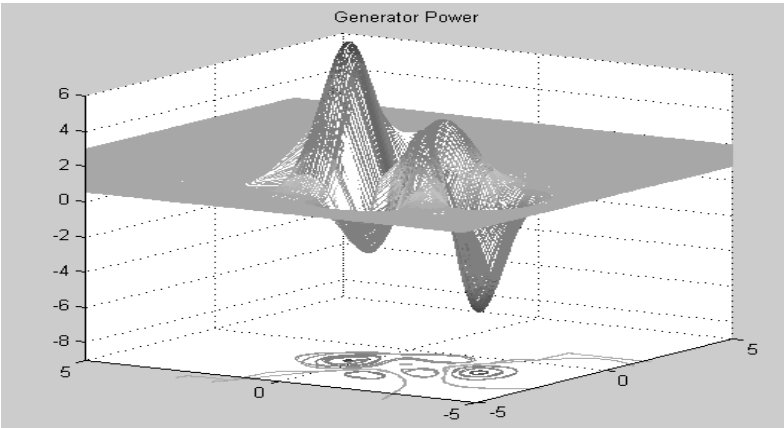

Fig. 6 – Generator power 3-D distribution for the most efficient driving cycle (DC1).

3. Conclusions

Hardware in the Loop and Model in the Loop analysis are very powerful methods for system design and validation. This paper offered an overview about these techniques applied to hybrid and electric vehicles and proposed a new performance analysis method.

A model based analysis of hybrid electric vehicle architecture was performed. A set of test cases were executed using this model that helped the system understanding. The model used can be incorporated in Hardware in the Loop test system for additional measurements. The parameterization of the model can be extended, and further analysis can be done in order to improve the model performance. An objective for further research is to extend and improve additional simulation models for electric vehicles that can be used for model in the loop simulations and that can be easily incorporated in HIL systems.

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METODĂ DE ANALIZĂ CU MODEL ÎN BUCLĂ ÎNCHISĂ APLICATĂ ÎN AUTOVEHICULE HIBRIDE ŞI ELECTRICE

(Rezumat)

Se prezintă o nouă metodă integrată pentru analiza performanţelor vehiculelor electrice şi hibride. Această metodă ia în considerare factorul de accelerare şi decelerare care influenţează eficienţa energetică. Cercetarea se bazează pe modelare Matlab şi pe conceptul „Hardware in the Loop”. Valoarea adăugată este dată de precizia modelului, care este parte a simulării, împreună cu noile metodele de analiză a performanţelor. Un set de 10 studii de caz sunt propuse şi eficienţa metodei este dovedită printr-o serie de rezultate de simulare. Motivaţia cercetării este dată de faptul că flota actuală de vehicule electrice şi hibride se confruntă cu multe provocări în ceea ce priveşte distanţa parcursă, ceea ce face exploatarea eficientă a energiei să fie un factor critic. Avantajul acestei metode este faptul că performanţa sistemelor poate fi validată în mare măsură de la un stadiu incipient. Rezultatele pot contribui la nevoia practică de a dezvolta vehicule hibride şi electrice, cu o eficienţă energetică mai mare şi cu un cost mai bun.