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SIMULATION OF A HYBRID VEHICLE PROPELLER MOVED TO ETHANOL

Arthur Ferreira Rezende Delfim
Universidade Federal de Minas Gerais – UFMG
Presidente Antonio Carlos Avenue, 6627, Pampulha, Belo Horizonte – MG, Brazil. ZIP: 31270-901
Department of Mechanical Engineering Post Graduation
arthurdelfim@me.com

Frederico Luiz de Carvalho Moura
FCA Group – Fiat Chrysler Automobiles
R. Gasming, 208-432 - Distrito Industrial Paulo Camilo Sul, Betim – MG
frederico.moura@fcagroup.com

Gabriel Mendes de Almeida Carvalho
Bruno Silva de Lima
Rafael Megale de Oliveira
Universidade Federal de Minas Gerais – UFMG
Presidente Antonio Carlos Avenue, 6627, Pampulha, Belo Horizonte – MG, Brazil. ZIP: 31270-901
Department of Mechanical Engineering Post Graduation
gmendescarvalho@gmail.com; bulinha07@hotmail.com; rmegale@hotmail.com

Abstract. *Against the backdrop of growing demand for fuels with lower polluting potential, ethanol is a feasible option for internal combustion engines, given its categorization as a renewable energy source, in addition to the inferior generation of polluting gases in its use and production cycle. However, due to the unsatisfactory performance of Otto engines, especially at low speeds, hybrid technology offers a solution. Therefore, what is projected in this work is a hybrid system composed by an electric motor associated with an internal combustion engine of the Otto cycle driven by ethanol, in which, it is important to highlight, there is a relevant potential for efficiency gain, and consequent decrease in fuel consumption, and also for emissions reduction. In order to validate this proposal, a simulation is done in ADVISOR (Advanced Vehicle Simulator), a computational vehicle analysis tool, in a way to allow a comparison between hybrid electric vehicles and conventional ones. Thus, considering the advantages of this system, it is proposed an alternative to diesel or gasoline engines..*

Keywords: Propeller; Hybrid; Vehicle; Simulation.

1. INTRODUCTION

The year 2015 marked the most comprehensive global climate convention, known as the Paris Conference (COP21-Paris), in which the 195 member countries of the UNFCCC signed the document " Paris Agreement " committing to establish guidelines and targets to reduce emissions of pollutants. The Paris Agreement theoretically replaces the 1997 Kyoto Protocol, the first and only international legal treaty setting greenhouse gas emission reduction targets, and which has definitely shown catastrophic results of increase by 50% in the period. Given this situation, hybrid electric vehicles (HEV) are part of the solution and are already a reality in some European countries, where the fossil fuel price is much higher than in Brazil or in the US.

Examples of these countries are Norway and the Netherlands, where the automobile industry has been transforming and adapting to the new conditions of fuel efficiency and low emissions of pollutants. Norway, for example, already has a fleet of HEVs and pure electric vehicles (PEVs) that composes almost 25% of the country's total market share, placing it as the world leader in this segment in terms of relative numbers (ICCT, 2015).

There is, in this sense, a clear trend towards lower fuel consumption and lower emissions in the European automotive market, as shown by Figure 1.

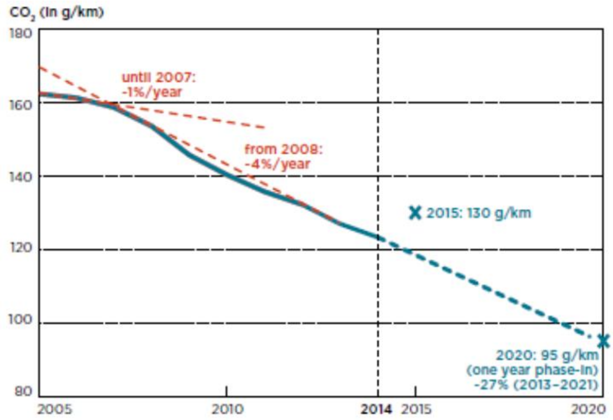

Figure 1. Carbon Dioxide emission evolution in Europe (ICCT, 2015)

Besides the impacts on the environment, the gas pollutants from the combustion of motor engines also can harm human health. According to studies by the Experimental Atmospheric Pollution Laboratory of the Medical School at the University of São Paulo (USP), approximately 3000 people die each year in the São Paulo Metropolitan Region due to air pollution-related diseases (Saldiva *et al*., 2007). Another study carried out by different universities and medical schools in the USA, with a population of almost 450 thousand people in 96 municipalities, shows that in regions with high concentration of ozone in the troposphere, typical at high traffic density areas and consequent emission of pollutants such as nitrous oxides (NOx) and hydrocarbons (HC), the probability of a person dying from respiratory diseases is as high as 30%. The research, which lasted more than 30 years, also reveals that nearly 8 million people die each year from respiratory causes in the world (Jerrett *et al*., 2009).

Many researches (Lukic, 2004; Koot, 2005) show HEV as the most promising technology, where it fits as an intermediary stage between the internal combustion engines and the pure electric vehicles. This is because the hybrid solution has fewer limitations and more flexibility than pure electric, in addition for being more consolidated. The objective of this work is to present an efficient ethanol hybrid vehicle fuel system with an improved torque curve in relation to Otto-type internal combustion engines, specifically with the scope of simulating the hybrid system by the ADVISOR software.

The deployment of this ethanol-powered hybrid vehicle system could generate an overall gain in propeller efficiency, a reduction in fuel consumption and emissions as well. These characteristics become more relevant considering the current scenario of climate change mobilization and investments in transport optimization. In this sense, there is real potential for hybrid technology to be able to reduce environmental impacts and eventually replace other less polluting and less efficient propulsion sources.

2. LITERATURE REVIEW

Internal combustion engines are defined as thermal machines in which, through the combustion of a mixture of air and fuel, chemical energy is converted into thermal energy that translates a portion of it into mechanical energy (Basshuysen, 2002). According to Heywood (1988), in the case of internal combustion engines (ICE), the fuel is burned or oxidized and the energy released into the engine, contrary to what occurs in external combustion engines. ICEs are currently the most widely used engines in the world for the transportation of cargoes and persons, mainly due to the energy and high power available relatively to a small mass.

Electric motors have a number of advantages over internal combustion engines such as zero emissions, oil independence, quiet operation, and superior efficiency (Ehsani, 2010). In the case of electric motors there are basically two functions: ensure the propulsion of the vehicle by converting mechanical energy into electrical energy, or alternatively to act as a generator storing electrical energy (Chan, 2007).

The main requirements for electric motors vehicle application include: high power density and instant power; high torque at low speeds and high power at high speeds; wide range of speeds, including regions of constant torque and constant power; quick torque response; high efficiency in wide range of speed and torque; high efficiency for regenerative brake; robustness and reliability for different operating conditions of the vehicle; and cost (Zeraoulia, 2006).

Hybrid systems consist of the association of an internal combustion engine (ICE) with an electric motor (EM). A more formal definition, according to UNECE (United Nations Economic for Europe), is that a hybrid electric vehicle (HEV) consists of a vehicle provided with a propulsion mechanism driven by at least one fuel, in addition to an electric power converter and electric energy storage systems. There are basically three ways or configurations for coupling ICE with EM: serial, parallel, and serial-parallel. The present work focuses its research on the parallel architecture as it corresponds to the prototype used.

In the parallel architecture, as shown by Figure 2, the electric and internal combustion engines are mechanically coupled on the same axis, so that the torque can occur independently. In the case of regenerative braking, the ICE is decoupled and the EM works as a generator, transforming the kinetic energy of the vehicle into charge for the batteries. The main advantages of this type of architecture includes: lower energy losses with conversions, since both engines (ICE and EM) are able to supply torque to the wheels; compact due to the absence of a generator, and also for having smaller traction components (typical applications are the compact vehicles class). Nevertheless, this arrange implicates some disadvantages such as: complex structure and control mechanism; higher costs; and as the ICE is connected directly to the wheels the optimum operating region is compromised.

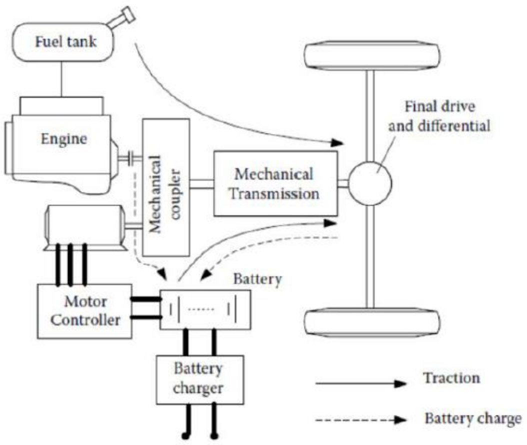

Figure 2. Hybrid Propeller Parallel System Configuration (Ehsani, 2010)

3. METHODOLOGY

This work is part of a project that involves the development of an ethanol-fueled hybrid automotive propulsion engine in which electrical engineering and mechanical engineering concepts are aligned together in order to propose an alternative to fossil fuels such as diesel and gasoline, still widely used in the automobile industry. The proposed system consists of an induction EM, with power less than 20kW (medium hybrid), coupled with an architecture parallel to an ICE of low-displacement Otto cycle (1.0L).

The main point of the prototype under development would be the implementation of the flat torque curve for the hybrid system, so that at low rotations the electric induction motor would overcome the torque deficiency, what is typically found in Otto engines.

Depending on the speed and rotation, the necessary torques (traction torque, brake braking torque and braking motor torque) are calculated. From the traction torque, the commands for the electric motor (EM) and internal combustion engine (ICE) torque will be computed, and the total torque will be stored for comparison with the traction reference torque. The reference ethanol ICE is a FIAT Fire 1.0L 8V (two valves per cylinder) spark ignition (Otto cycle), "flex-fuel" engine, has a maximum power (with ethanol) of 86hp (63,25kW) at 5.500rpm and maximum torque (with ethanol) of 12.5 kgf.m (122,6Nm) at 4000rpm. The EM is a high-speed (7.200rpm), three-phase, 220V, 240Hz, 10kW induction electric motor (IEM). Figure 3 shows the test bench.

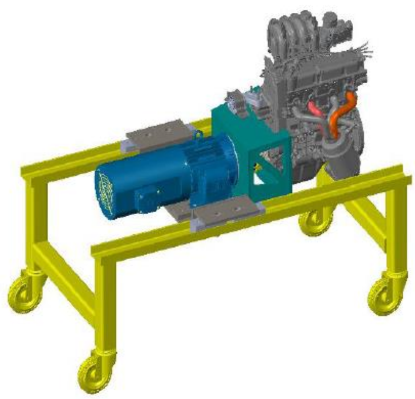

Figure 3. Test Bench on Solid Works Software

Three simulations were performed. The first considered a conventional vehicle, composed of a gasoline internal combustion engine, present in the ADVISOR library. The simulation model, shown by Figure 4, is named as "VEH_SMCAR", which the software classifies as small car and is based on Saturn SL1 (1994). The gasoline ICE 1.0L Geo Metro 1991 weights 1191kg; presents a maximum power of 41kW at 5700rpm; maximum torque of 81N.m at 3477rpm; efficiency peak of 34%; drag coefficient of 0,335 and front area of 2m².

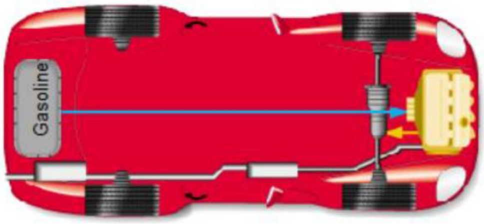

Figure 4. Conventional Vehicle representation model on ADVISOR software

Transmission data, post-exhaust treatment and accessories were defined as the default values of the simulator and are represented at Figure 5 diagram.

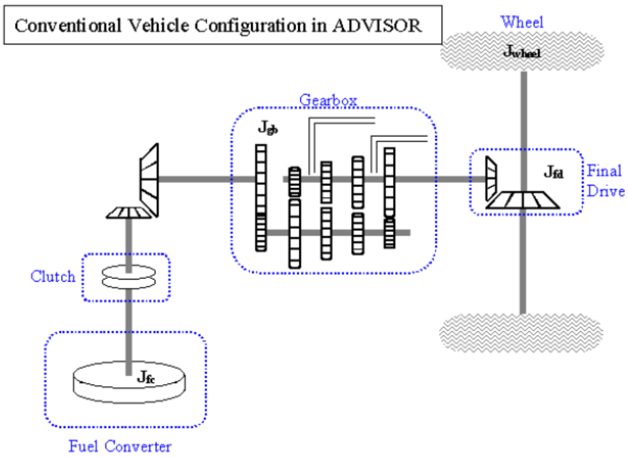

Figure 5. Conventional Vehicle Configuration Diagram on ADVISOR software

For the simulation of the hybrid electric vehicle, the Honda Insight 2000 model according to Figure 6 was chosen – data from ADVISOR library - since this vehicle has an architecture similar to what is predicted for the final prototype. It is a parallel architecture in which the EM and the ICE are mounted on the same axis (transmission ratio equal to one). The gasoline ICE Honda Insight 1.0L weights 1000kg; presents a maximum power of 50kW at 5700rpm; maximum torque of 89,5N.m at 4800rpm; efficiency peak of 40%; drag coefficient of 0,25 and front area of 1,9m². The parallel architecture diagram is presented at Figure 7.

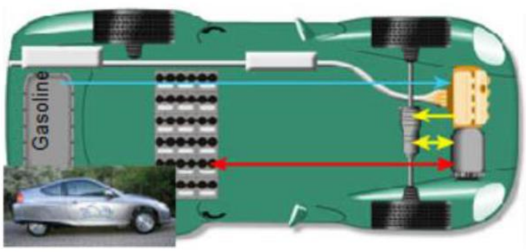

Figure 6. Hybrid Vehicle representation model on ADVISOR software fueled with gasoline

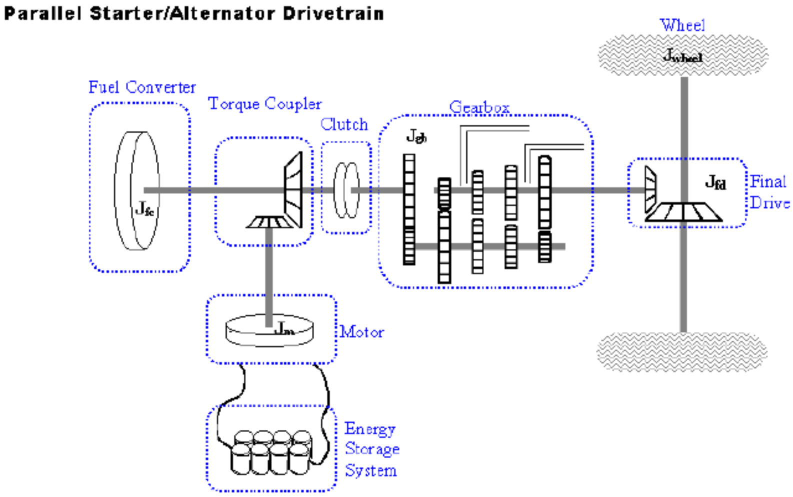

Figure 7. Parallel Architecture Diagram Configuration on ADVISOR software

Finally, the third simulation utilized the previously mentioned ICE FIAT Fire 1.0L 8V fueled with ethanol on the same hybrid model of the ADVISOR software, as shown by Figure 8. The results were obtained from these data for a UDDS (Urban Drive Dynamometer Schedule) cycle test (first 10 cycles method).

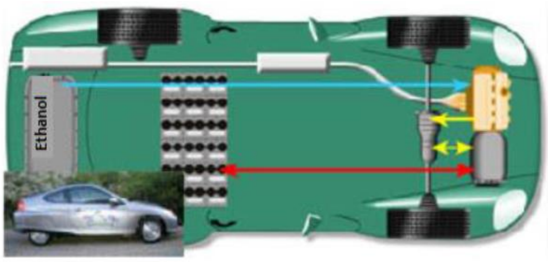

Figure 8. Hybrid Vehicle representation model on ADVISOR software fueled with ethanol

4. RESULTS AND DISCUSSION

The efficiency map for the ICE Geo 1.0L (41kW) of the first simulation model, according to NREL is shown by Figure 9. The results were generated for 10 vehicle cycles and the UDDS cycle is shown by Figure 10.

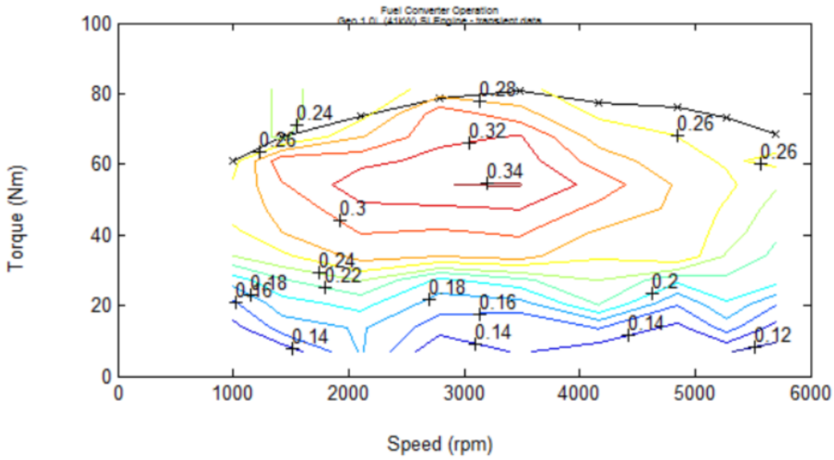

Figure 9. Efficiency Map for the ICE Geo 1.0L

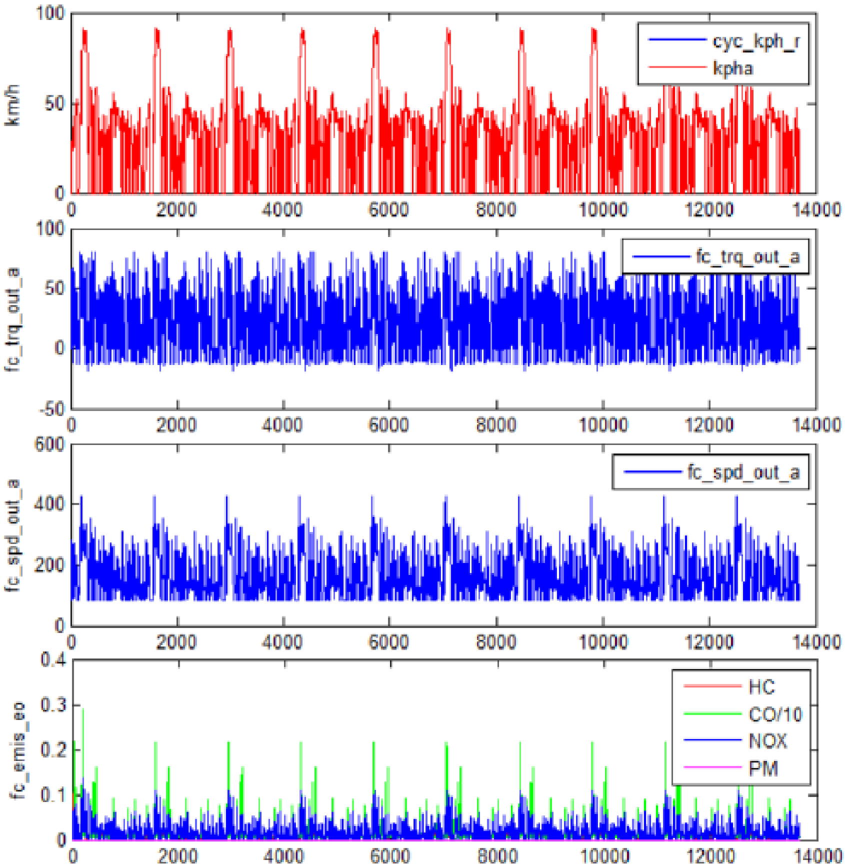

Figure 10. UDDS cycle result for the first simulation on ADVISOR software

- Fuel Consumption (L/100km): 6,2 (gasoline).
- Distance (km): 119,9.
- Global Efficiency: 9,7%.
- ICE Mean Efficiency: 22.64%.

The efficiency map for the ICE Honda Insight 1.0L (50kW) is presented at Figure 11. It is coupled with the EM induction electric motor (10kW) which has the efficiency map of Figure 12. The results were also generated for 10 vehicle cycles and the UDDS (Urban Drive Dynamometer Schedule) cycle is shown by Figure 13.

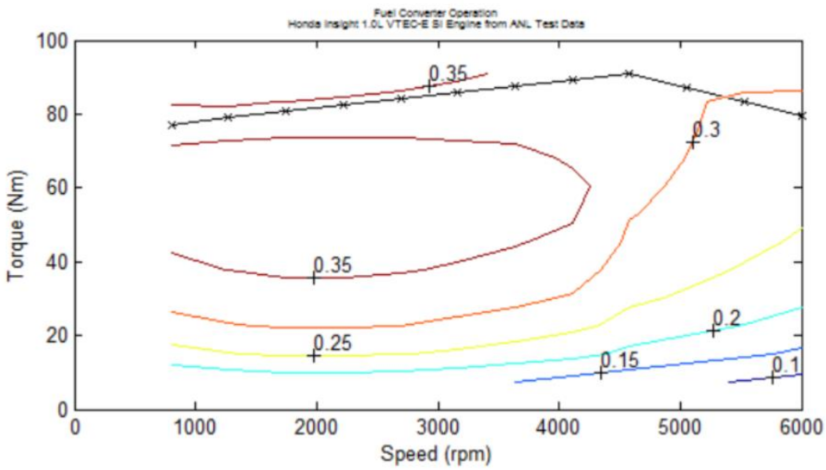

Figure 11. Efficiency Map for gasoline Honda Insight 1.0L VTEC-E

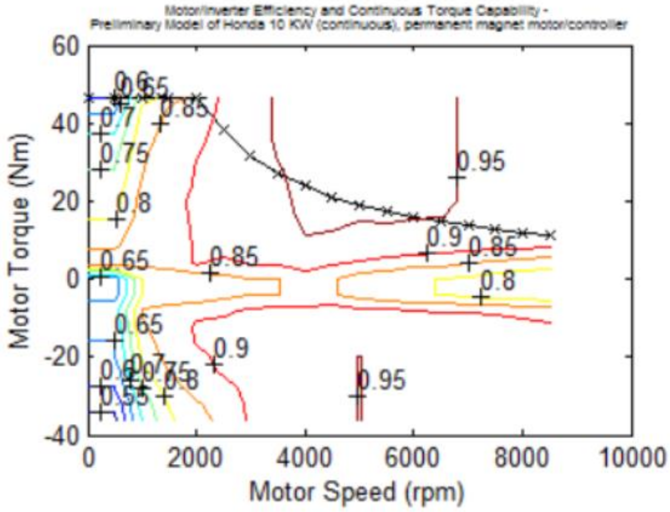

Figure 12. Efficiency Map for Electric Motor of Permanent Magnet Honda 10kW

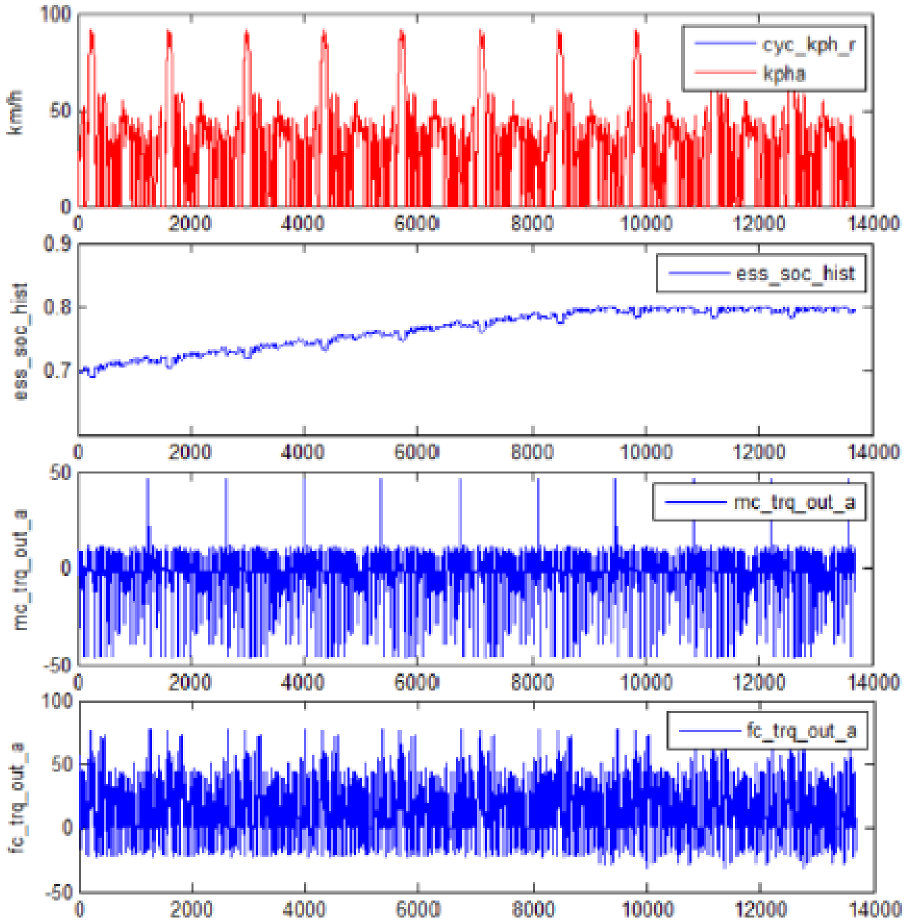

Figure 13. UDDS cycle result for the second simulation on ADVISOR software.
Note: I. Speed Developed vs. Required; II. State of charge (SOC); III. Torque EM (out); IV. Torque ICE (out).

- Fuel Consumption (L/100km): 3,6 (gasoline).
- Distance (km): 119,9.
- Global Efficiency: 10,0%.
- ICE Mean Efficiency: 24.34%.

Ultimately, corresponding to the third simulation model, the efficiency map for the ICE FIAT Fire 1.0L (63,25kW) is presented at Figure 14. It is coupled with the same EM induction electric motor (10kW) previously represented (Figure 12) for the second simulation data. The results were also generated for 10 vehicle cycles and the data from the UDDS (Urban Drive Dynamometer Schedule) cycle is shown by Figure 15.

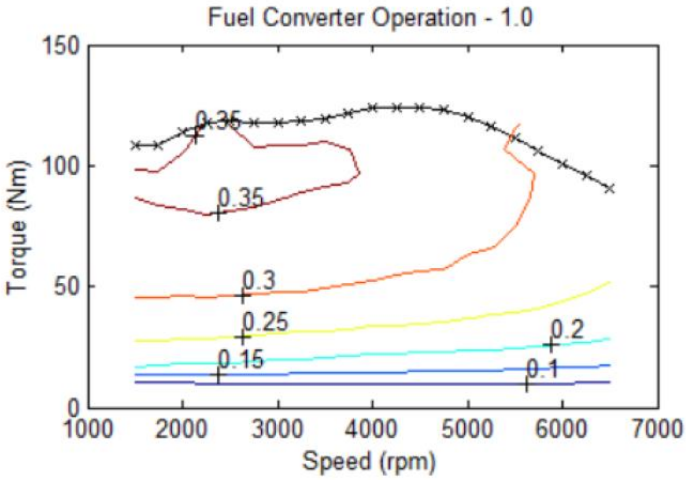

Figure 14. Efficiency Map for ethanol ICE FIAT Fire 1.0L (63,25kW)

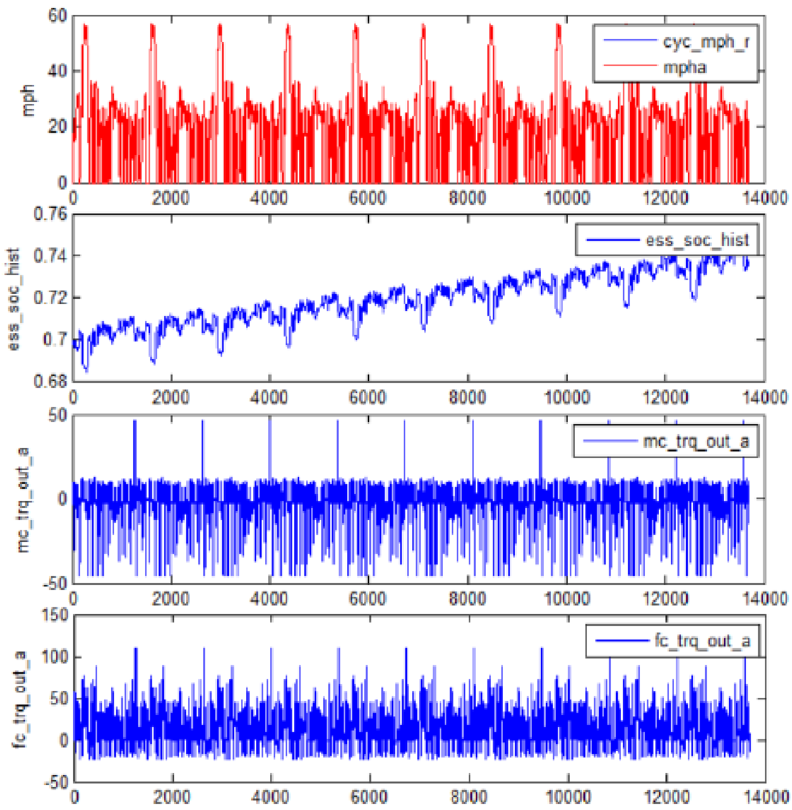

Figure 15. UDDS cycle result for the third simulation on ADVISOR software

- Fuel Consumption only with ICE (L/100km): 12,9 (ethanol).
- Fuel Consumption with EM coupled to the ICE (hybrid) (L/100km): 9,9 (ethanol).
- Gas equivalent (L/100km): 6,6 (gasoline)
- Distance (km): 119,9.
- Global Efficiency: 7,1% (ethanol ICE).
- ICE Mean Efficiency: 16.53% (ethanol ICE).

Table 1 summarizes the obtained results, including the FIAT ethanol fuel consumption and efficiency data to enable reduction comparison for the hybrid model, which global efficiency calculation could not be performed by instance.

Table 1. Simulation Main Results Summary

Engine	Fuel Consumption	Distance	Global Efficiency	ICE Mean Efficiency
GEO (gas) Baseline	6,2	119,9km	9,7%.	22,64%
HONDA (gas) Hybrid	3,6	119,9km	10,0%.	24.34%.
FIAT (ethanol) baseline	8,6	-	7,1%	16.53%
FIAT (ethanol) Hybrid	6,6	119,9km	-	-

The fuel consumption reduced drastically comparing the pure gasoline engine (First Simulation) to the hybrid gasoline motor (Second Simulation), it decayed from 6,2L/100km to 3,6L/100km, what represents almost 42% of total reduction. For the ethanol model (third simulation) the fuel consumption (gasoline equivalent for better comparison) was reduced from 8,6L/100km to 6,6L/100km, what represents over 23% decay.

It can be analyzed that during the cycles there was an increase in the state of charge of the batteries (13-II), what is confirmed as well by the plot of Figure 13-III, in which the EM presents negative torque values (loading state). This fact suggests even a point of improvement that could be implemented, because the control logic could be adjusted by more requisition of the EM, so that the specific consumption remained constant or with a small decrease, which would imply an increase in the efficiency of the propellant set.

The results found for the Honda Insight with ICE Fiat 1.0L moved 100% to ethanol (third simulation) were very similar to those of the second simulation, but with lower values of fuel economy and efficiency.

5. CONCLUSIONS

The results showed the effectiveness of the hybrid technology in terms of the efficiency of the propeller assembly and also the potential of fuel reduction, especially in urban cycles. An interesting fact to note is that in addition to improving fuel efficiency, the hybrid technology also revealed a significant gain in vehicle power. Simulation 2 evidenced this increase of power with the supplementation of torque by the electric machine with the achievement of expressively shorter times in the performance test (0-100km/h).

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Basshuysen, R.; Shäfer, F. Internal Combustion Engine Handbook - Basics, Components, Systems, and Perspectives, 2002.

Chan, C. The State of the Art of Electric, Hybrid, and Fuel Cell Vehicles. Proceedings of the IEEE, 95(4): p.704-718, 2007.

Ehsani, M.; Gao, Y.; Emadi, A. Modern Electric Hybrid Electric and Fuel Cell Vehicles Fundamentals, Theory and Design. 2nd Edition, 2010.

Heywood, J. B. Internal combustion engine fundamentals. 1 ed. New York McGraw- Hill, Inc., 1988. 930 p.

Jerrett, M. et al. Long-Term Ozone Exposure And Mortality. Journal of Medicine, New England, v. 360, n. 11, p. 1085-1095, 12 Mar, 2009.

Koot, M. et al. Energy management strategies for vehicular electric power systems, IEEE Transactions on vehicular technology, vol. 54, no. 3, 2005.

Lukic, S. M. and Emadi, A. Effects of Drivetrain Hybridization on Fuel Economy and Dynamic Performance of Parallel Hybrid Electric Vehicles, IEEE Transactions on vehicular technology, vol. 53, no. 2, 2004.

Saldiva, P. H. N. et al. Programa de Controle de Emissões Veiculares (Proconve) – Emissões de poluentes atmosféricos por fontes móveis e estimativa dos efeitos em saúde na RMSP: cenário atual e projeções. São Paulo: USP/Laboratório de Poluição Atmosférica Experimental da Faculdade de Medicina da USP, 2007.

Zeraoulia, M., Benbouzid, M., Diallo, D. Electric Motor Drive Selection Issues for HEV Propulsion Systems: A Comparative Study. IEEE Transactions on Vehicular Technology, Vol. 55 No 6, November 2006. IEEE, 2006.

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